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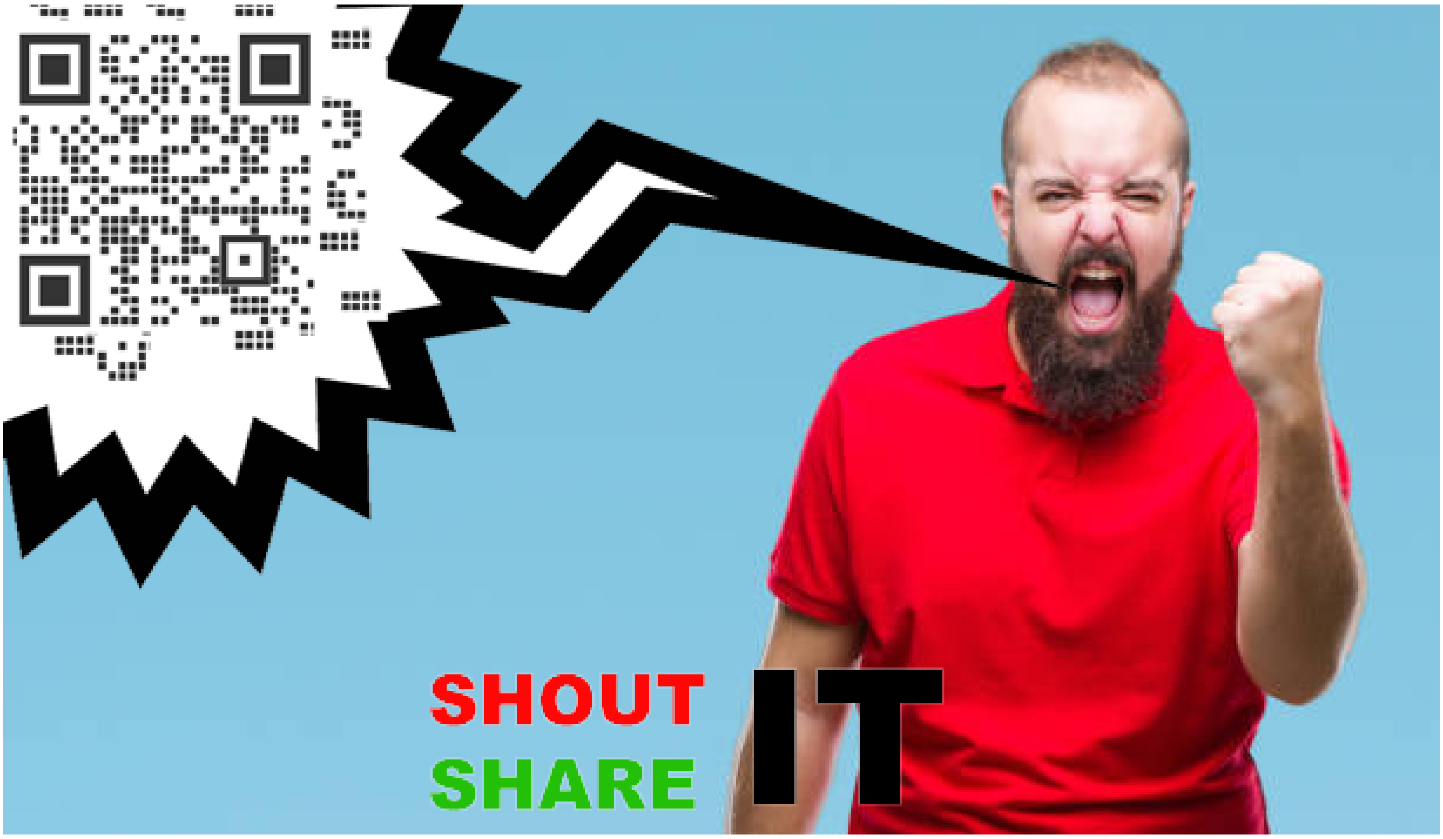
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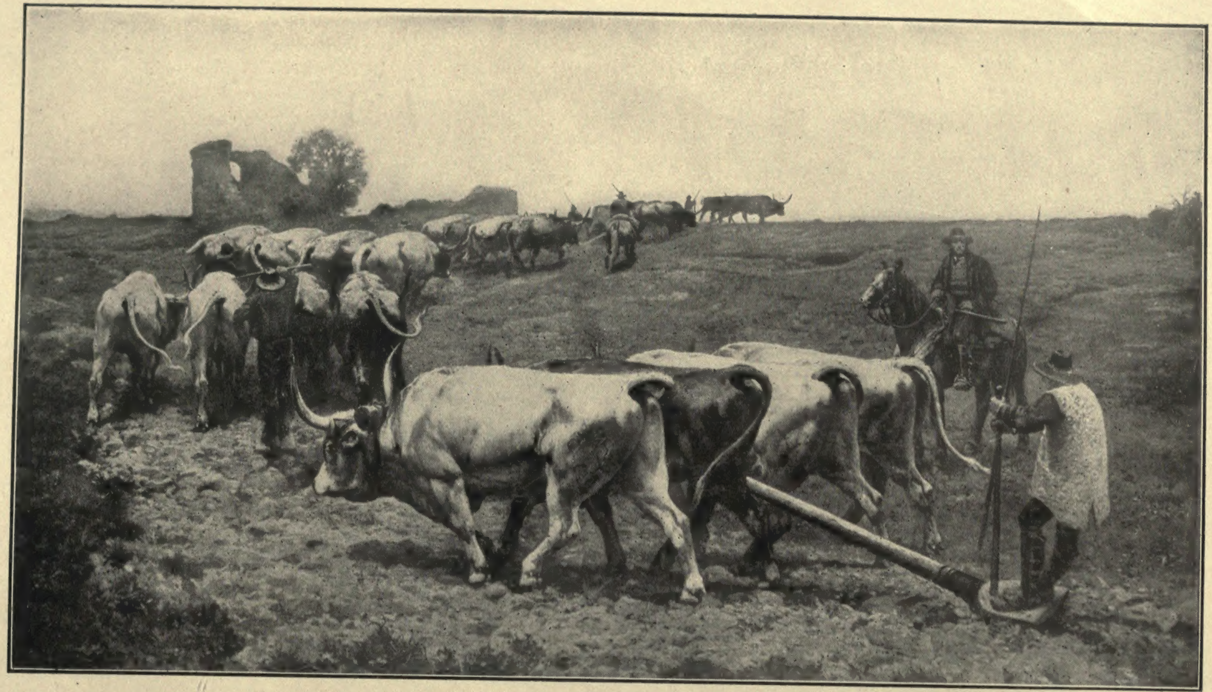

A PRIMITIVE USE OF THE ANIMAL MACHINE THAT IS STILL IN VOGUE IN MANY EUROPEAN COUNTRIES.

(From the painting by J. Didier, in the *Musée du Luxembourg*, Paris.)

History of science

EVERY-DAY SCIENCE

BY
HENRY SMITH WILLIAMS, M.D., LL.D.
ASSISTED BY
EDWARD H. WILLIAMS, M.D.

VOLUME VI

THE CONQUEST OF NATURE

ILLUSTRATED

NEW YORK AND LONDON
THE GOODHUE COMPANY
PUBLISHERS ➻ MDCCCCIX

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THE CONQUEST OF NATURE

IN the earlier volumes we have been concerned with the growth of knowledge. For the most part the scientific delvers whose efforts have held our attention have been tacitly unmindful, or even explicitly contemptuous, of the influence upon practical life of the phenomena to the investigation of which they have devoted their lives. They were and are obviously seekers of truth for the mere love of truth.

But the phenomena of nature are not dissociated in fact, however much we may attempt to localize and classify them. And so it chances that even the most visionary devotee of abstract science is forever being carried into fields of investigation trenching closely upon the practicalities of every-day life. A Black investigating the laws of heat is preparing the way explicitly, however unconsciously, for a Watt with his perfected mechanism of the steam engine.

Similarly a Davy working at the Royal Institution with his newly invented batteries, and intent on the discovery of new elements and the elucidation of new principles, is the direct forerunner of Jablochkoff, Brush, and Edison with their commercial revolution in the production of artificial light.

Again Oersted and Faraday, earnestly seeking out the fundamental facts as to the relations of electricity and magnetism, invent mechanisms which, though they seem but laboratory toys, are the direct forerunners of the modern dynamos that take so large a share in the world's work.

In a word, all along the line there is the closest association between what are commonly called the theoretical sciences and what with only partial propriety are termed the applied sciences. The linkage of one with the other must never be forgotten by anyone who would truly apprehend the status of those practical sciences which have revolutionized the civilization of the nineteenth and twentieth centuries in its most manifest aspects.

Nevertheless there is, to casual inspection, a somewhat radical distinction between theoretical and practical aspects of science—just as there are obvious differences between two sides of a shield. And as the theoretical aspects of science have largely claimed our attention hitherto, so its practical aspects will be explicitly put forward in the pages that follow. In the present volume we are concerned with those primitive applications of force through which man early learned to add to his working efficiency, and with the elaborate mechanisms—turbine wheels, steam engines, dynamos—through which he has been enabled to multiply his powers until it is scarcely exaggeration to say that he has made all Nature subservient to his will. It is this view which justifies the title of the volume, which might with equal propriety have been termed the Story of the World's Work.

THE CONQUEST OF NATURE

I

MAN AND NATURE

"YOUNG men," said a wise physician in addressing a class of graduates in medicine, "you are about to enter the battle of life. Note that I say the 'battle' of life. Not a playground, but a battlefield is before you. It is a hard contest—a battle royal. Make no mistake as to that. Your studies here have furnished your equipment; now you must go forth each to fight for himself."

The same words might be said to every neophyte in whatever walk of life. The pursuit of every trade, every profession is a battle—a struggle for existence and for supremacy. Partly it is a battle against fellow men; partly against the contending powers of Nature. The physician meets rivalry from his brothers; but his chief battle is with disease. In the creative and manufacturing fields which will chiefly concern us in the following volumes, it is the powers of Nature that furnish an ever-present antagonism.

No stone can be lifted above another, to make the crudest wall or dwelling, but Nature—represented by her power of gravitation—strives at once to pull it down again. No structure is completed before the elements are at work defacing it, preparing its slow but certain ruin. Summer heat and winter cold expand and contract materials of every kind; rain and wind wear and warp and twist; the oxygen of the air gnaws into stone and iron alike;—in a word, all the elements are at work undoing what man has accomplished.

THE STRUGGLE FOR EXISTENCE

In the field of the agriculturist it is the same story. The earth which brings forth its crop of unwholesome weeds so bountifully, resists man's approaches when he strives to bring it under cultivation. Only by the most careful attention can useful grains be made to grow where the wildlings swarmed in profusion. Not only do wind and rain, blighting heat and withering cold menace the crops; but weeds invade the fields, the germs of fungoid pests lurk everywhere; and myriad insects attack orchard and meadow and grain field in devastating legions.

Similarly the beasts which were so rugged and resistant while in the wild state, become tender and susceptible to disease when made useful by domestication. Aforetime they roamed at large, braving every temperature and thriving in all weathers. But now they must be housed and cared for so tenderly that they become, as Thoreau said, the keepers of men, rather than kept by men, so much more independent are they than their alleged owners. Tender of constitution, domesticated beasts must be housed, to protect them from the blasts in which of yore their forebears revelled; and man must slave day in and day out to prepare food to meet the requirements of their pampered appetites.

He must struggle, too, to protect them from disease, and must care for them in time of illness as sedulously as he cares for his own kith and kin. Truly the ox is keeper of the man, and the seeming conquest that man has wrought has cost him dear.

But of course the story has another side. After all, Nature is not so malevolent as at first glance she seems. She has opposed man at every stage of his attempted progress; yet at the same time she has supplied him all his weapons for waging war upon her. Her great power of gravitation opposes every effort he makes; yet without that same power he could do nothing—he could not walk or stay upon the earth even; and no structure that he builds would hold in place for an instant.

So, too, the wind that smites him and tears at his handiwork, may be made to serve the purposes of turning his windmills and supplying him with power.

The water will serve a like purpose in turning his mills; and, changed to steam with the aid of Nature's store of coal, will make his steam engines and dynamos possible. Even the lightning he will harness and make subject to his will in the telegraphic currents and dynamos.

And in the fields, the grains which man struggles so arduously to produce are after all no thing of his creating. They are only adopted products of Nature, which he has striven to make serve his purpose by growing them under artificial conditions. So, too, the domesticated beasts are creatures that belong in the wilds and in distant lands. Man has brought them, in defiance of Nature, to uncongenial climes, and made them serve as workers and as food-suppliers where Nature alone could not support them. Turn loose the cow and the horse to forage for themselves here in the inhospitable north, and they would starve. They survive because man helps them to combat the adverse conditions imposed by Nature, yet no one of them could live for an hour were not the vital capacities supplied by Nature still in control.

Everywhere, then, it is the opposing of Nature, up to certain limits, with the aid of Nature's own tools, that constitutes man's work in the world. Just in proportion as he bends the elements to meet his needs, transforms the plants and animals, defies and exceeds the limitations of primeval Nature—just in proportion as he conquers Nature, in a word, is he civilized.

Barbaric man is called a child of Nature with full reason. He must accept what Nature offers. But civilized man is the child grown to adult stature, and able in a manner to control, to dominate—if you please to conquer—the parent.

If we were to seek the means by which developing man has gradually achieved this conquest, we should find it in the single word, Tools; that is to say, machines for utilizing the powers of Nature, and, as it were, multiplying them for man's benefit. So unique is the capacity that man exerts in this direction, that he has been described as "the tool-making animal." The description is absolutely accurate; it is inclusive and exclusive. No non-human animal makes any form of implement to aid it in performing its daily work; and contrariwise every human tribe, however low its stage of savagery, makes use of more or less crude forms of implements. There must have been a time, to be sure, when there existed a man so low in intelligence that he had not put into execution the idea of making even the simplest tool. But the period when such a man existed so vastly antedates all records that it need not here concern us. For the purpose of classifying all existing men, and all the tribes of men of which history and pre-historic archæology give us any record, the definition of man as the tool-making animal is accurate and sufficient.

At first thought it might seem that an equally comprehensive definition might describe man as the working animal. But a moment's consideration shows the fallacy of such a suggestion. Man is, to be sure, the animal that works effectively, thanks to the implements with which he has learned to provide himself; but he shares with all animate creatures the task of laboring for his daily necessities. This is indeed a work-a-day world, and no creature can live in it without taking its share in that perpetual conflict which bodily necessities make imperative. Most lower animals confine their work to the mere securing of food, and to the construction of rude habitations. Some, indeed, go a step farther and lay up stores of food, in chance burrows or hollow trees; a few even manufacture relatively artistic and highly effective receptacles, as illustrated by the honeycomb made by the bees and their allies. Again, certain animals, of which the birds are the best representatives, construct temporary structures for the purpose of rearing their young that attain a relatively high degree of artistic perfection. The Baltimore oriole weaves a cloth of vegetable fibre that is certainly a wonderful texture to be made with the aid of claws and bill alone. It may be doubted whether human hands, unaided by implements, could duplicate it. But it is crude enough compared with even the coarsest cloth which barbaric races manufacture with the aid of implements.

So it is with any comparison of animal work with the work of man, in whatever field. The crudest human endeavor is superior to the best non-human efforts; and the explanation is found always in the fact that the ingenuity of man has enabled him to find artificial aids that add to his power of manipulation. So large a share have these artificial aids taken in man's evolution, that it has long been customary, in studying the development of civilization, to make the use of various types of implements a test of varying stages of human progress.

SCIENCE AND CIVILIZATION

The student of primitive life assures us, basing his statements on the archæological records, that there was a time when the most advanced of mankind had no tools made of better material than chipped stone. By common consent that time is spoken of as the Rough Stone Age.

We are told that then in the course of immeasurable centuries man learned to polish his stone implements, doubtless by rubbing them against another stone, or perhaps with the aid of sand, thus producing a new type of implement which has given its name to the Age of Smooth or Polished Stone.

Then after other long centuries came a time when man had learned to smelt the softer metals, and the new civilization which now supplanted the old, and, thanks to the new implements, advanced upon it immeasurably, is called the Age of Bronze.

At last man learned to accomplish the wonderful feat of smelting the intractable metal, iron, and in so doing produced implements harder, sharper, and cheaper than his implements of bronze; and when this crowning feat had been accomplished, the Age of Iron was ushered in.

By common consent, students of the history of the evolution of society accept these successive ages, each designated by the type of implements with which the world's work was accomplished, as representing real and definite stages of human progress, and as needing no better definition than that supplied by the different types of implements.

Could the archæologist trace the stream of human progress still farther back toward its source, he would find doubtless that there were several great epochal inventions preceding the time of the Rough Stone Age, each of which was in its way as definitive and as revolutionary in its effects upon society, as these later inventions which we have just named. To attempt to define them clearly is to enter the field of uncertainty, but two or three conjectures may be hazarded that cannot be very wide of the truth.

It is clear, for example, that if we go back in imagination to the very remotest ancestors of man that can be called human, we must suppose a vast and revolutionary stage of progress to have been ushered in by the first race of men that learned to make habitual use of the simplest implement, such as a mere club. When man had learned to wield a club and to throw a stone, and to use a stone held in the hand to break the shell of a nut, he had attained a stage of culture which augured great things for the future. Out of the idea of wielded club and hurled stone were to grow in time the ideas of hammer and axe and spear and arrow.

Then there came a time—no one dare guess how many thousands of years later—when man learned to cover his body with the skin of an animal, and thus to become in a measure freed from the thraldom of the weather. He completed his enfranchisement by learning to avail himself of the heat provided by an artificial fire. Equipped with these two marvelous inventions he was able to extend the hitherto narrow bounds of his dwelling-place, passing northward to the regions which at an earlier stage of his development he dared not penetrate. Under stress of more exhilarating climatic conditions, he developed new ideals and learned to overcome new difficulties; developing both a material civilization and the advanced mentality that is its counterpart, as he doubtless never would have done had he remained subject to the more pampering conditions of the tropics.

The most important, perhaps, of the new things which he was taught by the seemingly adverse conditions of an inhospitable climate, was to provide for the needs of a wandering life and of varying seasons by domesticating animals that could afford him an ever-present food supply. In so doing he ceased to be a mere fisher and hunter, and became a herdsman. One other step, and he had conceived the idea of providing for himself a supply of vegetable foods, to take the place of that which nature had provided so bountifully in his old home in the tropics. When this idea was put into execution man became an agriculturist, and had entered upon the high road to civilization.

All these stages of progress had been entered upon prior to the time of which the oldest known remains of the cave-dweller give us knowledge. It were idle to conjecture the precise sequence in which these earliest steps toward civilization were taken, and even more idle to conjecture the length of time which elapsed between one step and its successor. But all questions of precise sequence aside, it is clear that here were four or five great ages succeeding one to another, that marked the onward and upward progress of our primeval ancestor before he achieved the stage of development that enabled him to leave permanent records of his existence. And—what is particularly significant from our present standpoint—it is equally clear that each of the great ages thus vaguely outlined was dependent upon an achievement or an invention that facilitated the carrying out of that scheme of never-ending work which from first to last has been man's portion. How to labor more efficiently, more productively; how to produce more of the necessaries and of the luxuries that man's physical and mental being demands, with less expenditure of toil—that from first to last has been the ever-insistent problem. And the answer has been found always through the development of some new species of mechanism, some new labor-saving device, some ingenious manipulation of the powers of Nature.

If, turning from the hypothetical period of our primitive ancestor, we consider the sweep of secure and relatively recent history, we shall find that precisely the same thing holds. If we contrast the civilization of Old Egypt and Babylonia—the oldest civilizations of which we have any secure record—with the civilization of to-day, we shall find that the differences between the one and the other are such as are due to new and improved methods of accomplishing the world's work.

Indeed, if we view the subject carefully, it will become more and more evident that the only real progress that the historic period has to show is such as has grown directly from the development of new mechanical inventions. The more we study the ancient civilizations the more we shall be struck with their marvelous resemblance, as regards mental life, to the civilization of to-day. In their moral and spiritual ideals, the ancient Egyptians were as brothers to the modern Europeans. In philosophy, in art, in literature, the

Age of Pericles established standards that still remain unexcelled. In all the subtleties of thought, we feel that the Greeks had reached intellectual bounds that we have not been able to extend.

But when, on the other hand, we consider the material civilization of the two epochs, we find contrasts that are altogether startling. The little world of the Greeks nestled about the Mediterranean, bounded on every side at a distance of a few hundred leagues by a *terra incognita.* The philosophers who had reached the confines of the field of thought, had but the narrowest knowledge of the geography of our globe. They traversed at best a few petty miles of its surface on foot or in carts; and they navigated the Mediterranean Sea, or at most coasted out a little way beyond the Pillars of Hercules in boats chiefly propelled by oars. By dint of great industry they produced a really astonishing number of books, but the production of each one was a long and laborious task, and the aggregate number indited during the Age of Pericles in all the world was perhaps not greater than an afternoon's output of a modern printing press.

In a word, these men of the classical period of antiquity, great as were their mental, artistic, and moral achievements, were as children in those matters of practical mechanics upon which the outward evidences of civilization depend. Should we find a race of people to-day in some hitherto unexplored portion of the earth—did such unexplored portions still exist—living a life comparable to that of the Age of Pericles, we should marvel no doubt at their artistic achievements, while at the same time regarding them as scarcely better than barbarians. Indeed this is more than unsupported hypothesis; for has it not been difficult for the Western world to admit the truly civilized condition of the Chinese, simply because that highly intellectual race of Orientals has not kept abreast of the Occidental changes in applied mechanics? Say what we will, this is the standard which we of the Western world apply as the test of civilization.

If, sweeping over in retrospect the history of the world since the time when the Egyptian and Babylonian civilizations were at their height, we attempt some such classification of the stages of progress as that which we a moment ago applied to pre-historic times, we shall be led to some rather startling conclusions. In the broadest view, it will appear that the age which ushered in the historic period continued unbroken by the advance of any great revolutionary invention throughout the long centuries of pre-Christian antiquity, and well into the so-called Middle Ages of our newer era. Then came the invention of gunpowder, or at least its introduction to the Western world—since the Chinaman here lays claim to vague centuries of precedence. Following hard upon the introduction of gunpowder, with its capacity to add to the destructive efficiency of man's most sinister form of labor, came a mechanism no less epoch-making in a far different field—the printing press.

But even these inventions, great as was their influence upon the progress of civilization, can scarcely be considered, it seems to me, as taking rank with the great epochal discoveries that gave their names to the preceding ages. Nor can any invention of the sixteenth or seventeenth century be hailed as really ushering in a new era. The invention for which that honor was reserved was a development of the eighteenth century; and did not come fully to its heritage until the early days of the nineteenth century. The invention was the application of steam to the purposes of mechanics. When this application was made, as wide a gap was crossed as that which separated the Stone Age from the Age of Metal; then the epoch in which the world was living when history begins was brought to a close, and a new era, the Age of Steam, was ushered in.

Scarcely had the world begun to adjust itself to the new conditions of the Age of Steam, when yet another power was made subservient to man's needs, and the Age of Steam was supplemented, not to say supplanted, by the Age of Electricity. Of course the new progressive movements did not necessarily imply elimination of old conditions; they imply merely the subordination of old powers to newer and better ones. Stone implements by no means ceased to have utility at once when metal implements came into vogue. Bronze long held its own against iron, and still has its utility. And iron itself finds but an added sphere of usefulness in the Age of Steam and Electricity.

All great changes are relatively slow. It is only as we look back upon them and view them in perspective that they seem cataclysmic. Gunpowder did not at once supplant the crossbow, and the cannon was long held to be inferior to the catapult. The printed book did not instantly make its way against the work of the scribe. Neither did the steam engine immediately supplant water power and the direct application of human labor. But in each case the new invention virtually rang the death knell of the old method from the hour of its inauguration, and the end was no less sure because it was delayed. And it requires no great powers of divination to foretell that in the coming age, the electric dynamo driven by water power may take the place of the steam engine. The Age of Steam may pass, with only at most a few generations of domination. And it is within the possibilities that the Age of Electricity will scarcely come into its own before it may be displaced by an Age of Radio-Activity. To press that point, however, would be to enter the field of prophecy, which is no part of my present purpose.

All that I have wished to point out is that for some thousands of years after man learned to make implements of iron, the industrial world and the human civilization that depends upon it, pursued a relatively static course, like a broad, sluggish current, with no new revolutionary discovery to impel it into new channels; and that then one revolutionary discovery succeeded another with bewildering suddenness, so that we of the early days of the twentieth century are farther removed, in an industrial way, from our forerunners of two hundred years ago, than those children of the eighteenth century were from the earliest civilization that ever developed on our globe. Indeed, this startling contrast would still hold true, were we to consider the newest era as compassing only the period of a single life. There are men living to-day who were born in that epoch when the steam engine was for the first time used to turn the wheels of factories. There are many men who can well remember the first practical application of steam to railway traffic. Hosts of men can remember when the first commercial message was transmitted by electricity along a wire. Even middle-aged men recall the first cable message that linked the old world with the new. And the application of the dynamo to the purposes of the world's work is an affair of but yesterday.

The historian of the future, casting his eye back across the long perspective of history, will find civilized man pursuing an even and unbroken course across the ages from the time of the pyramids of Egypt to about the time of the French Revolution. There will be no dearth of incident to claim his attention in the way of wars and conquests, and changing creeds, and the rise and fall of nations, each pursuing virtually the same course of growth and decay as all the others. But when he comes to the close of the eighteenth century, it will not be the social paroxysm of a nation, or the meteoric career of a Napoleon that will claim his attention so much as the introduction of that new method of utilizing the powers of Nature which found its expression in the mechanism called the steam engine.

If the name of any individual stands out as the great and memorable one of that epoch of transition, at which the static current of previous civilization changed suddenly to a Niagara-current of progress, it will be the name of the great scientific inventor, rather than that of the great military conqueror—the name of James Watt, rather than that of Napoleon.

The military conqueror had his day of surpassing glory and departed, to leave the world only a little worse than he found it. But the mechanical inventor left a heritage that was to add day by day to the wealth and happiness of humanity, supplying millions of artificial hands, and making possible such beneficent improvements as no previous age had dreamed of. Tasks that human hands had performed slowly, laboriously, and inadequately, were now to be performed swiftly, with ease, and well by the artificial hands provided with the aid of the new power. Where carts drawn by horses had toiled slowly across the land, and ships driven by the wind had drifted slowly through the waters, massive trains of cars were to hurtle to the four corners of the earth with inconceivable speed, and floating palaces were to course the waters with almost equal defiance to the limitations of time and space.

And then there came that still weirder conquest of time and space, wrought by the electric current. The moment when man first spoke with man from continent to continent in defiance of the oceans, marked the dawning of that larger day when all mankind shall constitute one brotherhood and all peoples but a single nation. Within a half century the sun of that new day has risen well above the horizon, and far sooner than even the optimist of to-day dare predict with certainty, it seems destined to reach its zenith.

But here again we verge upon the dangerous field of prophecy. Let us turn from it and cast an eye back across the most wonderful of centuries, contrasting the conditions of to-day in each of a half-dozen fields of the world's work, with the conditions that obtained at the close of the eighteenth century. Such a brief survey will show us perhaps more vividly than we could otherwise be shown, how vast has been the progress, how marvelous the development of civilization, in the short decades that have elapsed since the coming of the Age of Steam.

Let us pay heed first to the world of the agriculturist. Could we turn back to the days of our grandparents, we should find farming a very different employment from what it is to-day. For the most part the farmer operated but a few small fields; if he had thirty or forty acres of ploughed land, he found ample employment for his capacities. He ploughed his fields with the aid of either a yoke of oxen or a team of horses; he sowed his grain by hand; he cultivated his corn with a hoe; he reaped his oats and wheat with a cradle—a device but one step removed from a sickle; he threshed his grain with a flail; he ground such portion of it as he needed for his own use with the aid of water power at a neighboring mill; and such portion of it as he sold was transported to market, be it far or near, in wagons that compassed twenty or thirty miles a day at best. As regards live stock, each farmer raised a few cattle, sheep, and hogs, and butchered them to supply his own needs, selling the residue to a local dealer who supplied the non-agricultural portion of the neighborhood. Any live stock intended for a distant market was driven on foot across the country to its destination. Each town and city, therefore, drew almost exclusively for its supply from the immediately surrounding country.

To-day the small farmer has become almost obsolete, and the farms of the eastern states that were the nation's chief source of supply a century ago are largely allowed to lie fallow, it being no longer possible to cultivate them profitably in competition with the rich farm lands of the middle west. In that new home of agriculture, the farm that does not comprise two or three hundred acres is considered small; and large farms are those that number their acres by thousands. The soil is turned by steam ploughs; the grain is sown with mechanical seeders and planters; the corn is cultivated with a horse-drawn machine, having blades that do the work of a dozen men; harvesters drawn by three or four horses sweep over the fields and leave the grain mechanically tied in bundles; the steam thresher places the grain in sacks by hundreds of bushels a day; and this grain is hurried off in steam cars to distant mills and yet more distant markets.

Meantime the raising of live stock has become a special department, with which the farmer who deals in cereals often has no concern. The cattle roam over vast pastures and are herded in the winter for fattening in great droves, and protected from the cold in barns that, when contrasted with the sheds of the old-time farmer, seem almost palatial. When in marketable condition, cattle are no longer slaughtered at the farm, but are transported in cars to one of the few great centres, chief of which are the stock yards of Chicago and of Kansas City. At these centres, slaughter houses and meat-packing houses of stupendous magnitude have been developed, capable of handling millions of animals in a year. From these centres the meat is transported in refrigerator cars to the seaboards, and in refrigerator ships to all parts of the world. Beef that grew on the ranges of the far west may thus be offered for sale in the markets of New England villages, at a price that prohibits local competition.

A more radical metamorphosis in agricultural conditions than all this implies could not well be conceived. And when we recall once more that the agricultural conditions that obtained at the beginning of the nineteenth century were closely similar to those that obtained in each successive age for a hundred preceding centuries, we shall gain a vivid idea of the revolutionizing effects of new methods of work in the most important of industries. It is little wonder that in this short time the world has not solved to the satisfaction of the economists all the new problems thus so suddenly developed.

Turn now to the manufacturing world. In the days of our great-grandparents almost every household was a miniature factory where cotton and wool were spun and the products were woven into cloth. It was not till toward the close of the eighteenth century—just at the time when Watt was perfecting the steam engine—that Arkwright developed the spinning-frame, and his successors elaborated the machinery that made possible the manufacture of cloth in wholesale quantities; and the nineteenth century was well under way before the household production of cloth had been entirely supplanted by factory production. It is nothing less than pitiful to contemplate in imagination our great-great-grandmothers—and all their forebears of the long centuries—drudging away day after day, year in and year out, at the ceaseless task of spinning and weaving—only to produce, as the output of a lifetime of labor, a quantity of cloth equivalent perhaps to what our perfected machine, driven by steam, and manipulated by a factory girl, produces each working hour of every day. Similarly, carpets and quilts were of home manufacture; so were coats and dresses; and shoes were at most the product of the local shoemaker around the corner.

In the kitchen, food was cooked over the coals of a great fireplace or in the brick oven connected with that fireplace. Meat was supplied from a neighboring farm; eggs were the product of the housewife's own poultry yard; the son or daughter of the farmer milked the cow and drove her to and from the pasture; the milk was "set" in pans in the cellar—on a swinging shelf, preferably, to make it inaccessible to the rats; and twice a week the cream was made into butter in a primitive churn, the dasher of which was operated by the vigorous arm of the housewife herself, or by the unwilling arms of some one of her numerous progeny.

To give variety to the dietary, fruits grown in the local garden or orchard were preserved, each in its season, by the industrious housewife, and stored away in the capacious cellar; where also might be found the supply of home-grown potatoes, turnips, carrots, parsnips, and cabbages to provide for the needs of the winter. Fuel to supply the household needs, both for cooking and heating, was cut in the neighboring woodland, and carefully corded in the door-yard, where it provided most uncongenial employment for the youth of the family after school hours and of a Saturday afternoon.

The ashes produced when this wood was burned in the various fireplaces, were not wasted, but were carefully deposited in barrels, from which in due course lye was extracted by the simple process of pouring water over the contents of the barrel. Meantime scraps of fat from the table were collected throughout the winter and preserved with equal care; and in due course on some leisure day in the springtime—heaven knows how a leisure day was ever found in such a scheme of domestic economy!—the lye drawn from the ash-barrels and the scraps of fat were put into a gigantic kettle, underneath which a fire was kindled; with the result that ultimately a supply of soft soap was provided the housewife, with which her entire establishment, progeny included, could be kept in a state of relative cleanness.

The reader of these pages has but to cast his eye about him in the household in which he lives, and contrast the conditions just depicted with those of his every-day life, to realize what change has come over the aspects of household economy in the course of a short century. Nor need he be told in each of the various departments of which the activities are here outlined, that the changes which he observes have been due to the application of machinery in all the essential lines of work in question. We need not pause to detail the multitudinous devices for the economy of household labor which owe their origin to the same agency. There still remains, to be sure, enough of drudgery in the task of the housewife; yet her most strenuous day seems a mere playtime in comparison with the average day of her maternal forebear of three or four generations ago.

But we must not here pause for further outlines of a subject which it is the purpose of this and succeeding volumes to explicate in detail. All our succeeding chapters will but make it more clear how marvelous are the elaborations of method and of mechanism through which the world's work of to-day is accomplished. We shall consider first the mechanical principles that underlie work in general, passing on to some of the principal methods of application through which the powers of Nature are made available. We shall then take up in succession the different fields of industry. We shall ask how the work of the agriculturist is done in the modern world; how the multitudinous lines of manufacture are carried out; how transportation is effected; we shall examine the *modus operandi* of the transmission of ideas; we shall even consider that destructive form of labor which manifests itself in the production of mechanisms of warfare. As we follow out the stories of the all-essential industries we shall be led to realize more fully perhaps than we have done before, the meaning of work in its relations to human development; and in particular the meaning of modern work, as carried out with the aid of modern mechanical contrivances, in its relations to modern civilization.

The full force of these relations may best be permitted to unfold itself as the story proceeds. There is, however, one fundamental principle which I would ask the reader to bear constantly in mind, as an aid to the full appreciation of the importance of our subject. It is that in considering the output of the worker we have constantly to do with one form or another of property, and that property is the very foundation-stone of civilization. "It is impossible," says Morgan, in his work on Ancient Society, "to overestimate the influence of property in the civilization of mankind. It was the power that brought the Aryan and Semitic nations out of barbarism into civilization. The growth of the idea of property in the human mind commenced in feebleness and ended in becoming its master passion. Governments and laws are instituted with primary reference to its creation, protection, and enjoyment. It introduced human slavery in its production; and, after the experience of several thousand years, it caused the abolition of slavery upon the discovery that the freeman was a better property-making machine." If, then, we recall that without labor there is no property, we shall be in an attitude of mind to appreciate the importance of our subject; we shall realize, somewhat beyond the bounds of its more tangible and sordid relations, the essential dignity, the fundamental importance—in a word, the true meaning—of Work.

Undoubtedly there is a modern tendency to accept this view of the dignity of physical labor. At any rate, we differ from the savage in thinking it more fitting that man should toil than that his wife should labor to support him—though it cannot be denied that even now the number of physical toilers among women greatly exceeds the number of such toilers among men. But in whatever measure we admit this attitude of mind, there can be no question that it is exclusively a modern attitude. Time out of mind, physical labor has been distasteful to mankind, and it is a later development of philosophy that appreciates the beneficence of the task so little relished.

The barbarian forces his wife to do most of the work, and glories in his own freedom. Early civilization kept conquered foes in thraldom, developing an hereditary body of slaves, whose function it was to do the physical work.

The Hebrew explained the necessity for labor as a curse imposed upon Father Adam and Mother Eve. Plato and Aristotle, voicing the spirit of the Greeks, considered manual toil as degrading.

To-day we hear much of the dignity of labor; but if we would avoid cant we must admit that now—scarcely less than in all the olden days—the physical toiler is such because he cannot help himself. Few indeed are the manual laborers who know any other means of getting their daily bread than that which they employ. The most strenuous advocates of the strenuous life are not themselves tillers of the soil or workers in factories or machine shops.

The farm youth of intelligence does not remain a farmer; he goes to the city, and we find him presently at the head of a railroad or a bank, or practising law or medicine. The more intelligent laborer becomes finally a foreman, and no longer handles the axe or sledge. We should think it grotesque were we to see a man of intellectual power obstinately following a pursuit that cost him habitual physical toil. When now and then a Tolstoi offers an exception to this rule, we feel that he is at least eccentric; and we may be excused the doubt whether he would follow the manual task cheerfully if he did not know that he could at any moment abandon it. It is because he knows that the world understands him to be only a dilettante that he rejoices in his task.

After all, then, judged by the modern practice, rather than by the philosopher's precept, the old Hebrew and Greek ideas were not so far wrong. Using the poetical language which was so native to them, it might be said that the necessity for physical labor is a curse —a disgrace.

A partial explanation of this may be found in the fact that the most uncongenial tasks are also the worst paid, while the congenial tasks command the high emoluments. Generally speaking there is no distinction between one laborer and another in the same field—except where the eminently fair method of piece work can be employed. Even the skilled laborer is usually paid by the day, and the amount he is to receive is commonly fixed by a Union regardless of his efficiency as compared with other laborers of the same class. And there is no possibility of his receiving any such sums as the man who plans the work, but does nothing with his own hands.

It has always been so. Just as "those who think must govern those that toil," so the thinker must command the high reward. Partly this is because man, considered as a mere toiler, is so relatively inefficient a worker. When he strives to work with his hands, his effort is but a pitiful one; he can by no possibility compete (as regards mere quantity of labor) with the ox and the horse. He is impatient of his own puerile efforts. It is only when he brings the products of ingenuity to his aid that he is able to show his superiority, and to justify his own egotism. So it is that in every age he has striven to find means of adding to his feeble powers of body through the use of his relatively gigantic powers of mind. And in proportion as he thus is able to "make his head work for his hands" as the saying goes, he verges toward the heights of civilization. To accomplish this more and more fully has ever been the task of science as applied to the industries.

It will be our object in the ensuing chapters to inquire how far science has accomplished the protean task thus set for it. We shall see that much has been done; but that much still remains to be done. In proportion as the problems are unsolved, science is reproached for its shortcomings—and stimulated to new efforts.

In proportion as labor has been minimized and production increased—in just that proportion has science justified itself; and in the same proportion has the Conquest of Nature been carried toward completion.

II

HOW WORK IS DONE

THE word energy implies capacity to do work. Work, considered in the abstract, consists in the moving of particles of matter against some opposing force, or in aid of previously acting forces. In the last analysis, all energy manifests itself either as a push or as a pull. But there is a modification of push and pull which is familiar to everyone in practice under the name of prying. Illustrations may be seen on every hand, as when a workman pries up a stone, or when a housewife pries up a tack with the aid of a hammer. The principle here involved is that of the lever—a principle which in its various practical modifications is everywhere utilized in mechanics. Very seldom indeed is the direct push or pull utilized; since the modified push or pull, as represented by the lever in its various modifications of pulley, ratchet-wheel, and the like, has long been known to meet the needs of practical mechanics.

The very earliest primitive man who came to use any implement whatever, though it were only a broken stick, must have discovered the essential principle of the lever, though it is hardly necessary to add that he did not know his discovery by any such high-sounding title. What he did know, from practical experience, was that with the aid of a stick he could pry up stones or logs that were much too heavy to be lifted without this aid.

This practical knowledge no doubt sufficed for a vast number of generations of men who used the lever habitually, without making specific study of the relations between the force expended, the lengths of the two ends of the lever, and the weight raised. Such specific experiments were made, however, more than two thousand years ago by the famous Syracusan, Archimedes. He discovered—or if some one else had discovered it before him, he at least recorded and so gains the credit of discovery—the specific laws of the lever, and he also pointed out that levers, all acting on the same principle, may be different as to their practical mechanism in three ways.

First, the fulcrum may lie between the power and the weight, as in the case of the balance with which we were just experimenting. This is called a lever of the first class, and familiar illustrations of it are furnished by the poker, steelyard, or a pair of scissors. The so-called extensor muscles of the body—those for example, that cause the arm to extend—act on the bones in such a way as to make them levers of this first class.

The second type of lever is that in which the weight lies between the force and the fulcrum, as illustrated by the wheelbarrow, or by an ordinary door.

In the third class of levers the power is applied between weight and fulcrum, as illustrated by a pair of tongs, the treadle of a lathe, or by the flexor muscles of the arm, operating upon the bones of the forearm.

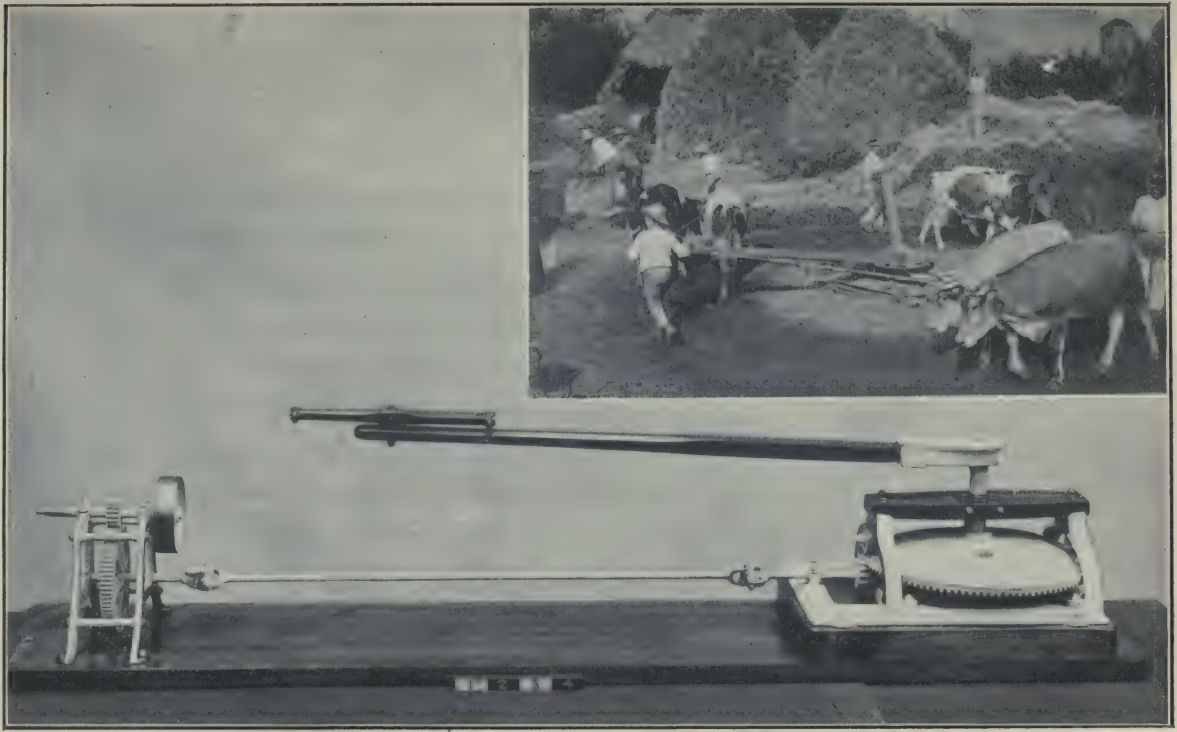
But in each case, let it be repeated, precisely the same principles are involved, and the same simple law of the relations between positions of power, weight, and fulcrum are maintained. The practical result is always that a weight of indefinite size may be moved by a power indefinitely long. If one arm of the lever is ten times as long as the other, the power of one pound will lift or balance a ten-pound weight; if the one arm is a thousand times as long as the other the power of one pound will lift or balance a thousand pounds. If the long arm of the lever could be made some millions of miles in length, the power that a man could exert would balance the earth.

How fully Archimedes realized the possibilities of the lever is illustrated in the classical remark attributed to him, that, had he but a fulcrum on which to place his lever, he could move the world. As otherwise quoted, the remark of Archimedes was that, had he a place on which to stand, he could move the world, a remark which even more than the other illustrates the full and acute appreciation of the laws of motion; since, as we have already pointed out, action and reaction being equal, the most infinitesimal push must be considered as disturbing even the largest body.

Tremendous as is the pull of gravity by which the earth is held in its orbit, yet the smallest push, steadily applied from the direction of the sun, would suffice ultimately to disturb the stability of our earth's motion, and to push it gradually through a spiral course farther and farther away from its present line of elliptical flight. Or if, on the other hand, the persistent force were applied from the side opposite the sun, it would suffice ultimately to carry the earth in a spiral course until it plunged into the sun itself. Indeed it has been questioned in modern times whether it may not be possible that precisely this latter effect is gradually being accomplished, through the action of meteorites, some millions of which fall out of space into the earth's atmosphere every day. If these meteorites were uniformly distributed through space and flying in every direction, the fact that the sun screens the earth from a certain number of them, would make the average number falling on the side away from the sun greater, and thus would in the course of ages produce the result just suggested. All that could save our earth from such a fate would be the operation of some counteracting force. Such a counteracting force is perhaps found in solar radiation. It may be added that the distribution of meteorites in space is probably too irregular to make their influence on the earth predicable in the present state of science; but the principle involved is no less sure.

WHEELS AND PULLEYS

Returning from such theoretical applications of the principle of motion, to the practicalities of every-day mechanisms, we must note some of the applications through which the principle of the lever is made available. Of these some of the most familiar are wheels, and the various modifications of wheels utilized in pulleys



HORSE AND CATTLE POWER.

The large picture shows a model of a familiar mechanism for utilizing horse power. The small picture shows a similar apparatus in actual operation, actuated by cattle, in contemporary Brittany.

and in cogged and bevelled gearings. A moment's reflection will make it clear that the wheel is a lever of the first class, of which the axle constitutes the fulcrum. The spokes of the wheel being of equal length, weights and forces applied to opposite ends of any diameter are, of course, in equilibrium. It follows that when a wheel is adjusted so that a rope may be run about it, constituting a simple pulley, a mechanism is developed which gives no gain in power, but only enables the operator to change the direction of application of power. In other words, pound weights at either end of a rope passed about a simple pulley are in equilibrium and will balance each other, and move through equal distances in opposite directions.

If, however, two or more pulley wheels are connected, to make the familiar apparatus of a compound pulley, we have accomplished by an interesting mechanism a virtual application of the principle of the long and short arm of the lever, and the relations between the weight at the loose end of the rope and the weight attached to the block which constitutes virtually the short end of the lever, may be varied indefinitely, according to the number of pulley-wheels that are used. A pound weight may be made to balance a thousand-pound weight; but, of course, our familiar principle still holding, the pound weight must move through a distance of a thousand feet in order to move a thousand-pound weight through a distance of one foot. Familiar illustrations of the application of this principle may be seen on every hand; as when, for example, a piano or a safe is raised to the upper window of a building by the efforts of men whose power, if directly expended, would be altogether inefficient to stir the weight.

The pulley was doubtless invented at a much later stage of human progress than the simple lever. It was, however, well known to the ancients. It was probably brought to its highest state of practical perfection by Archimedes, whose experiments are famous through the narrative of Plutarch. It will be recalled that Archimedes amazed the Syracusan general by constructing an apparatus that enabled him, sitting on shore, to drag a ponderous galley from the water. Plutarch does not describe in detail the apparatus with which this was accomplished, but it is obvious from his description of what took place, that it must have been a system of pulleys.

It will be observed that the pulley is a mechanism that enables the user to transmit power to a distance. But this indeed is true in a certain sense of every form of lever. Numberless other contrivances are in use by which power is transmitted, through utilization of the same principle of the lever, either through a short or through a relatively long distance. A familiar illustration is the windlass, which consists of a cylinder rotating on an axis propelled by a long handle, a rope being wound about the cylinder. This is a lever of the second class, the axis acting as fulcrum, and the rope operating about the circumference of the cylinder typifying the weight, which may be actually at a considerable distance, as in the case of the old-fashioned well with its windlass and bucket, or of the simple form of derrick sometimes called a sheerlegs.

OTHER MEANS OF TRANSMITTING POWER

Power is transmitted directly from one part of a machine to another, in the case of a great variety of machines, with the aid of cogged gearing wheels of various sizes. The modifications of detail in the application of these wheels may be almost infinite, but the principle involved is always the same. The case of two wheels toothed about the circumference, the teeth of the two wheels fitting into one another, illustrates the principle involved. A consideration of the mechanism will show that here we have virtually a lever fixed at both ends, represented by the radii of the two wheels, the power being applied through the axle of one wheel, and the weight, for purposes of calculation, being represented by the pressure of the teeth of one wheel upon those of the other. So this becomes a lever of the second class, and the relations of power between the two wheels are easily calculated from the relative lengths of the radii. If, for example, one radius is twice as long as the other, the transmission of power will be, obviously, in the proportion of two to one, and meantime the distance traversed by the circumference of one wheel will be twice as great as that traversed by the other.

A modification of the toothed wheel is furnished by wheels which may be separated by a considerable distance, and the circumferences of which are connected by a belt or by a chain. The principle of action here is precisely the same, the belt or chain serving merely as a means of lengthening out our lever. The relative sizes of the wheels, and not the length of the belt or chain, is the determining factor as regards the relative forces required to make the wheels revolve.

It is obvious all along, of course, since action and reaction are equal, that all of the relations in question are reciprocal. When, for example, we speak of a pound weight on the long end of a lever balancing a ten-pound weight on the short end, it is equally appropriate to speak of the ten-pound weight as balancing the one-pound weight. Similarly, when power is applied to the lever, it may be applied at either end. Ordinarily, to be sure, the power is applied at the long end, since the object is to lift the heavy weight; but in complicated machinery it quite as often happens that these conditions are reversed, and then it becomes desirable to apply strong power to the short end of the lever, in order that the relatively small weight may be carried through the long distance. In the inter-relations of gearing wheels, such conditions very frequently obtain, practical ends being met by a series of wheels of different sizes. But the single rule, already so often outlined, everywhere holds—wherever there is gain of power there is loss of distance, and we can gain distance only by losing power. The words gain and loss in this application are in a sense misnomers, since, as we have already seen, gain and loss are only apparent, but their convenience of application is obvious.

A familiar case in which there is first loss of speed and gain of power, and then gain of speed at the expense of power in the same mechanism, is furnished by the bicycle, where (1) the crank shaft turns the sprocket wheel that constitutes a lever of the second class with gain of power; where (2) power is further augmented through transmission from the relatively large sprocket wheel to the small sprocket of the axle; and where (3) there is great loss of power and corresponding gain of speed in transmitting the force from the small sprocket wheel at the axle to the rubber rim of the bicycle proper, this last transmission representing a lever of the third class. The net gain of speed is tangibly represented by the difference in distance traversed by the man's feet in revolving the pedals, and the actual distance covered by the bicycle.

INCLINED PLANES AND DERRICKS

A less obvious application of the principle of reciprocal equivalence of distance and weight is furnished by the inclined plane, a familiar mechanism with the aid of which a great gain of power is possible. The inclined plane, like the lever, has been known from remotest antiquity. Its utility was probably discovered by almost the earliest builders. Diodorus Siculus tells us that the great pyramids of Egypt were constructed with the aid of inclined planes, based on a foundation of earth piled about the pyramids. Diodorus, living at a period removed by some thousands of years from the day of the building of the pyramids, may or may not have voiced and recorded an authentic tradition, but we may well believe that the principle of the inclined plane was largely drawn upon by the mechanics of old Egypt, as by later peoples.

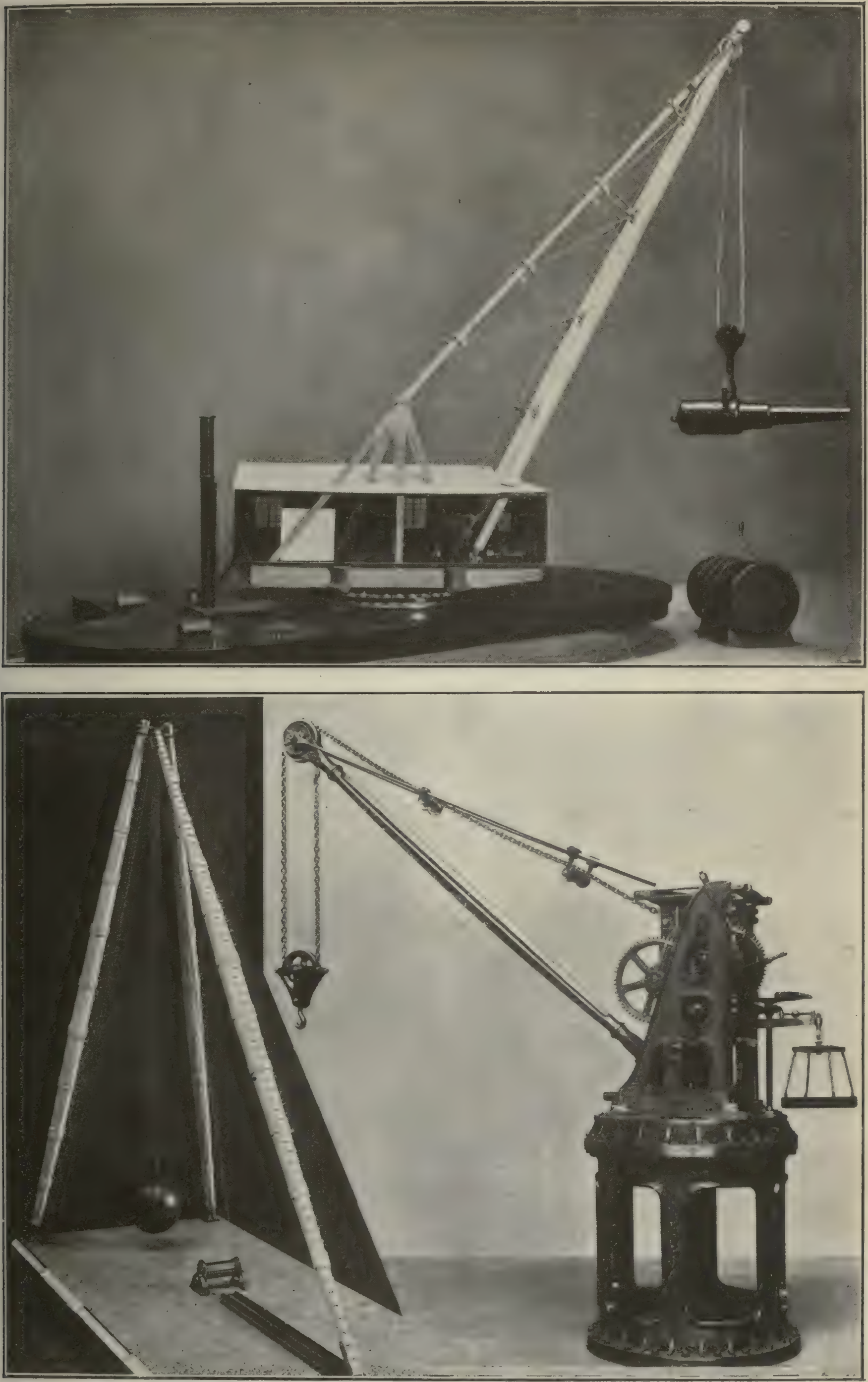
The law of the inclined plane is that in order to establish equilibrium between two weights, the one must be to the other as the height of the inclined plane is to its length. The steeper the inclined plane, therefore, the less will be the gain in power; a mechanical principle which familiar experience or the simplest experiment will readily corroborate.

In its elemental form the inclined plane is not used very largely in modern machinery, but its modified form of the wedge and the screw have more utility. The screw, indeed, which is obviously an inclined plane adjusted spirally about a cylinder or a cone, is familiar to everyone, and is constantly utilized in applying power.

The crane or derrick furnishes a familiar but relatively elaborate illustration of a mechanism for the transmission of power, in which all the various devices hitherto referred to are combined, without the introduction of any new principle.

Derricks have been employed from a very early day. The battering-rams of the ancient Egyptians and Babylonians, for example, were virtually derricks; and no doubt the same people used the device in raising stones to build their temples and city walls, and in putting into position such massive sculptures as the obelisks of Egypt and the monster graven bulls and lions of Nineveh and Babylon.

The modern derrick, made of steel, and operated by steam or electricity, capable of lifting tons, yet absolutely obedient to the hand of the engineer, is a really wonderful piece of mechanism. A steam-scoop,



CRANES AND DERRICKS.

The upper figure shows a floating derrick, the lower right-hand figure a combined derrick and weighing machine, and the lower left-hand figure a so-called sheerlegs, which is a

for example, excavating a gravel bank, seems almost a thing of intelligence; as it gores into the bank scooping up perhaps a half ton of earth, its upward sweeping head reminds one of an angry bull. Then as it swings leisurely about and discharges its load at just the right spot into an awaiting car, its hinged bottom swings back and forth two or three times before closing, with curious resemblance to the jaw of a dog; the similarity being heightened by the square bull-dog-headed shape of the scoop itself. Yet this remarkable contrivance, with all its massive steel beams and chains and cog wheels, employs no other principles than the simple ones of lever and pulley and inclined plane that we have just examined. The power that must be applied to produce a given effect may be calculated to a nicety. The capacities of the machine are fully predetermined in advance of its actual construction. But of course this is equally true of every other form of power-transmitter with which the modern mechanical engineer has to deal.

FRICTION

In making such calculations, however, there is an additional element which the engineer must consider, but which we have hitherto disregarded. In all methods of transmission of power, and indeed in all cases of the contact of one substance with another, there is an element of loss through friction. This is due to the fact that no substance is smooth except in a relative sense. Even the most highly polished glass or steel, when viewed under the microscope, presents a surface covered with indentations and rugosities. This granular surface of even seemingly smooth objects, is easily visualized through the analogy of numberless substances that are visibly rough. Yet the vast practical importance of this roughness is seldom considered by the casual observer. In point of fact, were it not for the roughened surface of all materials with which we come in contact, it would be impossible for any animal or man to walk, nor could we hold anything in our hands. Anyone who has attempted to handle a fish, particularly an eel, fresh from the water, will recall the difficulty with which its slippery surface was held; but it may not occur to everyone who has had this experience that all other objects would similarly slip from the hand, had their surfaces a similar smoothness. The slippery character of the eel is, of course, due in large part to the relatively smooth surface of its skin, but partly also to the lubricant with which it is covered. Any substance may be rendered somewhat smoother by proper lubrication; it is necessary, however, that the lubricant should be something which is not absorbed by the substance. Thus, wood is given increased friction by being moistened with oil, but, on the other hand, is made slippery if covered with graphite, soap, or any other fatty substances that it does not absorb.

Recalling the more or less roughened surface of all objects, the source of friction is readily understood. It depends upon the actual jutting of the roughened surfaces, one upon the other. It virtually constitutes a force acting in opposition to the motion of any two surfaces upon each other. As between any different materials, under given conditions, it varies with the pressure, in a definite and measurable rate, which is spoken of as the coefficient of friction for the particular substances. It is very much greater where the two substances slide over one another than where the one rolls upon the other, as in the case of the wheel. The latter illustrates what is called rolling friction, and in practical mechanics it is used constantly to decrease the loss—as, for example, in the wheels of wagons and cars. The use of lubricants to decrease friction is equally familiar. Without them, as everyone knows, it would be impossible to run any wheel continuously upon an axle at high speed for more than a very brief period, owing to the great heat developed through friction. Friction is indeed a perpetual antagonist of the mechanician, and we shall see endless illustrations of the methods he employs to minimize its influence. On the other hand, we must recall that were it rendered absolutely *nil*, his machinery would all be useless. The car wheel, for example, would revolve indefinitely without stirring the train, were there absolutely no friction between it and the rail.

AVAILABLE SOURCES OF ENERGY

We have pointed out that every body whatever contains a certain store of energy, but it has equally been called to our attention that, in the main, these stores of energy are not available for practical use. There are, however, various great natural repositories of energy upon which man is able to draw. The chief of these are, first, the muscular energy of man himself and of animals; second, the energy of air in motion; third, the energy of water in motion or at an elevation; and fourth, the molecular and atomic energies stored in coal, wood, and other combustible materials. To these we should probably add the energy of radio-active substances—a form of energy only recently discovered and not as yet available on a large scale, but which may sometime become so, when new supplies of radio-active materials have been discovered. It will be the object of succeeding chapters to point out the practical ways in which these various stores of energy are drawn upon and made to do work for man's benefit.

III

THE ANIMAL MACHINE

THE muscular system is not only the oldest machine in existence, but also the most complex. Moreover, it is otherwise entitled to precedence, for even to-day, in this so-called age of steam and electricity, the muscular system remains by far the most important of all machines. In the United States alone there are some twenty million horses doing work for man; and of course no machine of any sort is ever put in motion or continues indefinitely in operation without aid supplied by human muscles. All in all, then, it is impossible to overestimate the importance of this muscular machine which is at once the oldest and the most lasting of all systems of utilizing energy.

The physical laws that govern the animal machine are precisely similar to those that are applied to other mechanisms. All the laws that have been called to our attention must therefore be understood as applying fully to the muscular mechanism. But in addition to these the muscular system has certain laws or methods of action of its own, some of which are not very clearly understood.

The prime mystery concerning the muscle is its wonderful property of contracting. For practical purposes we may say that it has no other property; the sole function of the muscle is to contract. It can, of course, relax, also, to make ready for another contraction, but this is the full extent of its activities. A microscopic examination of the muscle shows that it is composed of minute fibres, each of which on contraction swells up into a spindle shape. A mass of such fibres aggregated together constitutes a muscle, and every muscle is attached at either extremity, by means of a tendon, to a bone. Both extremities of a muscle are never attached to the same bone—otherwise the muscle would be absolutely useless. Usually there is only a single bone between the two ends of a muscle, but in exceptional cases there may be more. As a rule, the main body of a muscle lies along the bone to which one end of it is attached, the other end of the muscle being attached to the contiguous bone placed not far from the point. The first bone, then, serves as a fulcrum on which the second bone moves as a lever, and, as already pointed out, the familiar laws of the lever operate here as fully as in the inanimate world. But a moment's reflection will make it clear that the object effected by this mechanism is the increase of motion with relative loss of energy. In other words, the muscular force is applied to the short end of the lever, and a far greater expenditure of force is required when the muscle contracts than the power externally manifested would seem to indicate.

A moment's consideration of the mechanism of the arm, having regard to the biceps muscle which flexes the elbow, will make this clear. If a weight is held in the hand it is perhaps twelve inches from the elbow.

If, while holding the weight, you will grasp the elbow with the other hand, you will feel the point of attachment of the biceps, and discover that it does not seem to be, roughly speaking, more than about an inch from the joint. Obviously, then, if you are lifting a pound weight, the actual equivalent of energy expended by the contracting biceps must be twelve pounds. But, in the meantime, when the pound weight in your hand moves through the space of one inch, the muscle has contracted by one-twelfth of an inch; and you may sweep the weight through a distance of two feet by utilizing the two-inch contraction, which represents about the capacity of the muscle.

A similar consideration of the muscles of the legs will show how the muscular system which is susceptible of but trifling variation in size, gives to the animal great locomotive power. With the aid of a series of levers, represented by the bones of our thighs, legs, and feet, we are able to stride along, covering three or four feet at each step, while no set of the muscles that effect this propulsion varies in length by more than two or three inches. It appears, then, that the muscular system gives a marvelous illustration of capacity for storing energy in a compact form and utilizing it for the development of motion.

THE TWO TYPES OF MUSCLES

The muscles of animals and men alike are divided into two systems, one called voluntary, the other involuntary. The voluntary muscles, as their name implies, are subject to the influence of the will, and under ordinary conditions contract in response to the voluntary nervous impulses. Certain sets of them, indeed, as those having to do with respiration, have developed a tendency to rhythmical action through long use, and ordinarily perform their functions without voluntary guidance. Their function may, however, become voluntary when attention is directed toward it, and is then subject to the action of the will within certain bounds. Should a voluntary attempt be made, however, to prevent their action indefinitely, the so-called reflex mechanism presently asserts itself. All of which may be easily attested by anyone who will attempt to stop breathing. All systems of voluntary muscles are subject to the influence of habit, and may assume activities that are only partially recognized by consciousness. As an illustration in point, the muscles involved in walking come, in the case of every adult, to perform their function without direct guidance of the will. Such was not the case, however, in the early stage of their development, as the observation of any child learning to walk will amply demonstrate. In the case of animals, however, even those muscles are so under the impress of hereditary tendencies as to perform their functions spontaneously almost from the moment of birth. These, however, are physiological details that need not concern us here. It suffices to recall that the voluntary muscles may be directed by the will, and indeed are always under what may be termed subconscious direction, even when the conscious attention is not directed to them.

The strictly involuntary muscles, however, are placed absolutely beyond control of the will. The most important of these muscles are those that constitute the heart and the diaphragm, and that enter into the substance of the walls of blood vessels, and of the abdominal organs. It is obvious that the functioning of these important organs could not advantageously be left to the direction of the will; and so, in the long course of evolution they have learned, as it were, to take care of themselves, and in so doing to take care of the organism, to the life of which they are so absolutely essential. As the physiologist views the matter, no organism could have developed which did not correspondingly develop such involuntary action of the vital organs. It will be seen that the involuntary muscles differ from the voluntary muscles in that they are not connected with bones. Instead of being thus attached to solid levers, they are annular in structure, and in contracting virtually change the size of the ring which their substance constitutes. Each fibre in contracting may be thought of as pulling against other fibres, instead of against a bony surface, and the joint action changes the size of the organ, as is obvious in the pulsing of the heart.

Though the rhythmical contractions of the involuntary muscles are independent of voluntary control, it must not be supposed that they are independent of the control of the central nervous mechanism. On the contrary, the nerve supply sent out from the brain to the heart and to the abdominal organs is as plentiful and as important as that sent to the voluntary muscles. There is a centre in the brain scarcely larger than the head of a pin, the destruction of which will cause the heart instantly to cease beating forever. From this centre, then, and from the other centres of the brain, impulses are constantly sent to the involuntary muscles, which determine the rate of activity. Nor are these centres absolutely independent of the seat of consciousness, as anyone will admit who recalls the varied changes in the heart's action under stress of varying emotions.

That the voluntary muscles are controlled by the central nervous mechanism needs no proof beyond the appeal to our personal experiences of every moment. You desire some object that lies on the table in front of you, and immediately your hand, thanks to the elaborate muscular mechanism, reaches out and grasps it. And this act is but typical of the thousand activities that make up our every-day life. Everyone is aware that the channel of communication between the brain and the muscular system is found in a system of nerves, which it is natural now-a-days to liken to a system of telegraph wires. We speak of the impulse generated in the brain as being transmitted along the nerves to the muscle, causing that to contract. We are even able to measure the speed of transfer of such an impulse. It is found to move with relative slowness, compassing only about one hundred and twelve feet per second, being in this regard very unlike the electric current with which it is so often compared. But the precise nature of this impulse is unknown. Its effect, however, is made tangible in the muscular contraction which it is its sole purpose to produce. The essential influence of the nerve impulse in the transaction is easily demonstrable; for if the nerve cord is severed, as often happens in accidents, the muscle supplied by that nerve immediately loses its power of voluntary contraction. It becomes paralyzed, as the saying is.

THE NATURE OF MUSCULAR ACTION

Paying heed, now, to the muscle itself, it must be freely admitted that, in the last analysis, the activities of the substance are as mysterious and as inexplicable as are those involved in the nervous mechanism. It is easy to demonstrate that what we have just spoken of as a muscle fibre consists in reality of a little tube of liquid protoplasm, and that the change in shape of this protoplasm constitutes the contraction of which we are all along speaking. But just what molecular and atomic changes are involved in this change of form of the protoplasm, we cannot say. We know that the power to contract is the one universal attribute of living protoplasm. This power is equally wonderful and equally inexplicable, whether manifested in the case of the muscle cell or in the case of such a formless single-celled creature as the amœba. When we know more of molecular and atomic force, we may perhaps be able to form a mental picture of what goes on in the structure of protoplasm when it thus changes the shape of its mass. Until then, we must be content to accept the fact as being the vital one upon which all the movements of animate creatures depend.

But if, here as elsewhere, the ultimate activities of molecules and atoms lie beyond our ken, we may nevertheless gain an insight into the nature of the substances involved. We know, for example, that the chief constituents of all protoplasm are carbon, hydrogen, oxygen, and nitrogen; and that with these main elements there are traces of various other elements such as iron, sulphur, phosphorus, and sundry salts. We know that when the muscle contracts some of these constituents are disarranged through what is spoken of as chemical decomposition, and that there results a change in the substance of the protoplasm, accompanied by the excretion of a certain portion of its constituents, and by the liberation of heat. Carbonic acid gas, for example, is generated and is swept away from the muscular tissues in the ever active blood-streams, to be carried to the lungs and there expelled —it being a noxious poison, fatal to life if retained in large quantities. Equally noxious are other substances such as uric acid and its compounds, which are also results of the breaking down of tissue that attends muscular action. In a word, there is an incessant formation of waste products, due to muscular activity, the removal of which requires the constant service of the purifying streams of blood and of the various excretory organs.

But this constant outflow of waste products from the muscle necessitates, of course, in accordance with the laws of the conservation of matter and of energy, an equally constant supply of new matter to take the place of the old. This supply of what is virtually fuel to be consumed, enabling the muscle to perform its work, is brought to the muscle through the streams of blood which flow from the heart in the arterial channels, and in part also through the lymphatic system. The blood itself gains its supply from the digestive system and from the lungs. The digestive system supplies water, that all-essential diluent, and a great variety of compounds elaborated into the proper pabulum; while the vital function of the lungs is to supply oxygen, which must be incessantly present in order that the combustion which attends muscular activity may take place. What virtually happens is that fuel is sent from the digestive system to be burned in the muscular system, with the aid of oxygen brought from the lungs.

In this view, the muscular apparatus is a species of heat engine. In point of fact, it is a curiously delicate one as regards the range of conditions within which it is able to act. The temperature of any given organism is almost invariable; the human body, for example, maintains an average temperature of $98\frac{2}{5}$ degrees, Fahrenheit. The range of variation from this temperature in conditions of health is rarely more than a fraction of a degree; and even under stress of the most severe fever the temperature never rises more than about eight degrees without a fatal result. That an organism which is producing heat in such varying quantities through its varying muscular activities should maintain such an equilibrium of temperature, would seem one of the most marvelous of facts, were it not so familiar.

The physical means by which the heat thus generated is rapidly given off, on occasion, to meet the varying conditions of muscular activity, is largely dependent upon the control of the blood supply, in which involuntary muscles, similar to those of the heart, are concerned. In times of great muscular activity, when the production of heat is relatively enormous, the arterioles that supply the surface of the body are rapidly dilated so that a preponderance of blood circulates at the surface of the body, where it may readily radiate its heat into space; the vast system of perspiratory ducts, with which the skin is everywhere supplied, aiding enormously in facilitating this result, through the secretion of a film of perspiration, which in evaporating takes up large quantities of heat.

The flushed, perspiring face of a person who has violently exercised gives a familiar proof of these physiological changes; and the contrary condition, in which the peripheral circulation is restricted, and in which the pores are closed, is equally familiar. Moreover, the same cutaneous mechanism is efficient in affording the organism protection from the changes of external temperature; though the human machine, thanks to the pampering influence of civilization, requires additional protection in the form of clothing.

APPLICATIONS OF MUSCULAR ENERGY

Having thus outlined the conditions under which the muscular machine performs its work, we have now to consider briefly the external mechanisms with the aid of which muscular energy is utilized. Of course, the simplest application of this power, and the one universally employed in the animal world is that in which a direct push or pull is given to the substance, the position of which it is desired to change. We have already pointed out that there is no essential difference between pushing and pulling. The fact receives another illustration in considering the muscular mechanism. We speak of pushing when we propel something away from a body, of pulling when we draw something toward it, yet, as we have just seen, each can be accomplished merely through the contraction of a set of muscles, acting on differently disposed levers. All the bodily activities are reducible to such muscular contractions, and the diversified movements in which the organism constantly indulges are merely due to the large number and elaborate arrangement of the bony levers upon which these muscles are operated.

We may well suppose that the primitive man continued for a long period of time to perform all such labors as he undertook without the aid of any artificial mechanism; that is to say, without having learned to gain any power beyond that which the natural levers of his body provided. A brief observation of the actions of a man performing any piece of manual labor will, however, quickly demonstrate how ingeniously the bodily levers are employed, and how by shifting positions the worker unconsciously makes the most of a given expenditure of energy. By bending the arms and bringing them close to the body, he is able to shorten his levers so that he can lift a much greater weight than he could possibly raise with the arms extended. On the other hand, with the extended arm he can strike a much more powerful blow than with the shorter lever of the flexed arm. But however ingenious the manipulation of the natural levers, a full utilization of muscular energy is possible only when they are supplemented with artificial aids, which constitute primitive pieces of machinery.

These aids are chiefly of three types, namely, inclined planes, friction reducers, and levers. The use of the inclined plane was very early discovered and put into practise in chipped implements, which took the form of the wedge, in such modifications as axes, knives, and spears of metal. All of these implements, it will be observed, consist essentially of inclined planes, adapted for piercing relatively soft tissues of wood or flesh, and hence serving purposes of the greatest practical utility.

The knife-blade is an extremely thin wedge, to be utilized by force of pushing, without any great aid from acquired momentum. The hatchet, on the other hand —and its modification the axe—has its blunter blade fastened to a handle; that the principle of the wedge may be utilized at the long end of a lever and with the momentum of a swinging blow. Ages before anyone could have explained the principle involved in such obscuring terms as that, the implement itself was in use for the same purpose to which it is still applied. Indeed, there is probably no other implement that has played a larger part in the history of human industry. Even in the Rough Stone Age it was in full favor, and the earliest metallurgists produced it in bronze and then in iron. The blade of to-day is made of the best tempered steel, and the handle or helve of hickory is given a slight curve that is an improvement on the straight handle formerly employed; but on the whole it may be said that the axe is a surviving primitive implement that has held its own and demonstrated its utility in every generation since the dawn, not of history only, but of barbarism, perhaps even of savagery.

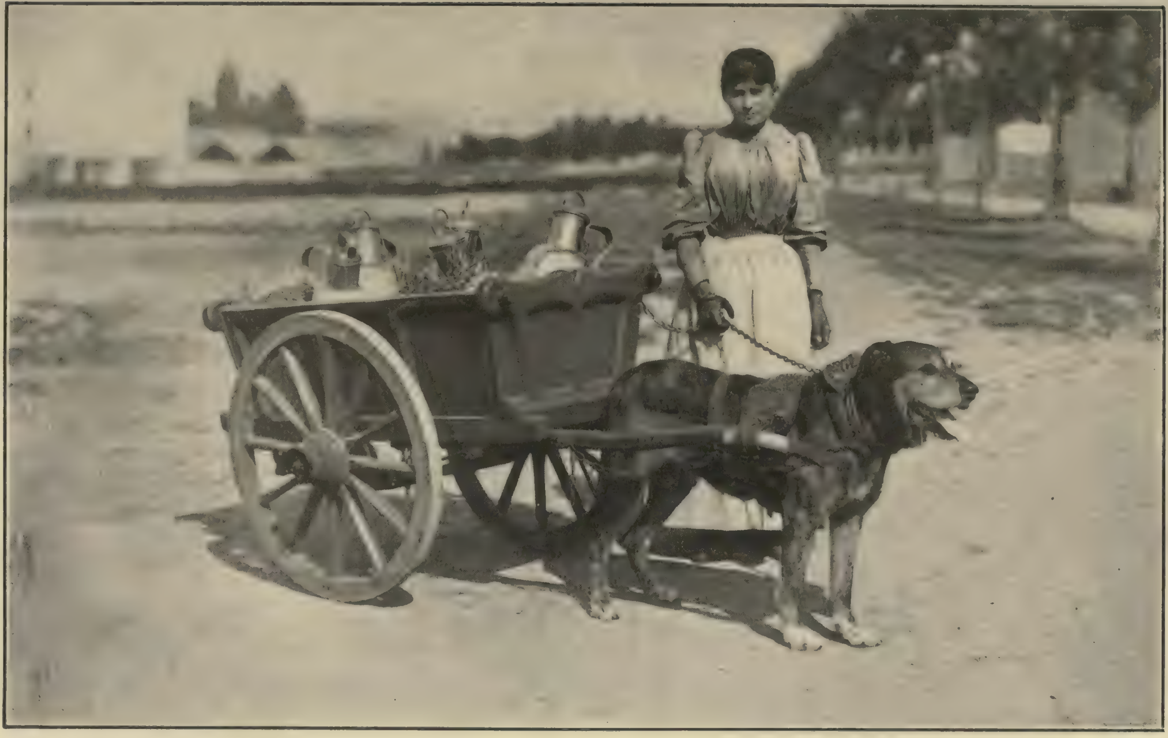
The saw, consisting essentially of a thin elongated blade, one ragged or toothed edge, is a scarcely less primitive and an equally useful and familiar application of the principle of the inclined plane—though it requires a moment's reflection to see the manner of application. Each tooth, however minute, is an inclined plane, calculated to slide over the tissue of wood or stone or iron even, yet to tear at the tissue with its point, and, with the power of numbers, ultimately wear it away.

THE WHEEL AND AXLE

The primitive friction reducer, which continues in use to the present day unmodified in principle, is the wheel revolving on an axle. Doubtless man had reached a very high state of barbarism before he invented such a wheel. The American Indian, for example, knew no better method than to carry his heavy burdens on his shoulders, or drag them along the ground, with at most a pair of parallel poles or runners to modify the friction; every move representing a very wasteful expenditure of energy. But the pre-historic man of the old world had made the wonderful discovery that a wheel revolving on an axle vastly reduces the friction between a weight and the earth, and thus enables a man or a woman to convey a load that would be far beyond his or her unaided powers. It is well to use both genders in this illustration, since among primitive peoples it is usually the woman who is the bearer of burdens. And indeed to this day one may see the women of Italy and Germany bearing large burdens on their backs and heads, and dragging carts about the streets, quite after the primitive method.

The more one considers the mechanism, the more one must marvel at the ingenuity of the pre-historic man who invented the wheel and axle. Its utility is sufficiently obvious once the thing has been done. In point of fact, it so enormously reduces the friction that a man may convey ten times the burden with its aid that he can without it. But how was the primitive man, with his small knowledge of mechanics, to predict such a result? In point of fact, of course, he made no such prediction. Doubtless his attention was first called to the utility of rolling bodies by a chance observation of dragging a burden along a pebbly beach, or over rolling stones. The observation of logs or round stones rolling down a hill might also have stimulated the imagination of some inventive genius.

Probably logs placed beneath heavy weights, such as are still employed sometimes in moving houses, were utilized now and again for many generations before the idea of a narrow section of a log adjusted on an axis was evolved. But be that as it may, this idea was put into practise before the historic period begins, and we find the earliest civilized races of which we have



A BELGIAN MILK-WAGON

In many of the countries of Europe the dog plays an important part as a beast of burden. Stringent laws are enforced in these countries to prevent possible abuse or neglect of the animals.

record—those, namely, of Old Egypt and of Old Babylonia—in full possession of the principle of the wheel as applied to vehicles. Modern mechanics have, of course, improved the mechanism as regards details, but the wheels depicted in Old Egyptian and Babylonian inscriptions are curiously similar to the most modern types. Indeed, the wheel is a striking illustration of a mechanism which continued century after century to serve the purposes of the practical worker, with seemingly no prospect of displacement.

MODIFIED LEVERS

For the rest, the mechanisms which primitive man learned early to use in adding to his working efficiency, and which are still used by the hand laborer, are virtually all modifications of our familiar type-implement, the lever. A moment's reflection will show that the diversified purposes of the crowbar, hoe, shovel, hammer, drill, chisel, are all accomplished with the aid of the same principles. The crowbar, for example, enables man to regain the power which he lost when his members were adapted to locomotion. His hands, left to themselves, as we have already pointed out, give but inadequate expression to the power of his muscles. But by grasping the long end of such a lever as the crowbar, he is enabled to utilize his entire weight in addition to his muscular strength, and, with the aid of this lever, to lift many times his weight.

The hoe, on the other hand, becomes virtually a lengthened arm, enabling a very slight muscular motion to be transformed into the long sweep of the implement, so that with small expenditure of energy the desired work is accomplished. Similarly, the sledge and the axe lengthen out the lever of the arms, so that great momentum is readily acquired, and with the aid of inertia a relatively enormous force can be applied. It will be observed that a laborer in raising a heavy sledge brings the head of the implement near his body, thus shortening the leverage and gaining power at the expense of speed; but extends his arms to their full length as the sledge falls, having now the aid of gravitation, to gain the full advantage of the long arm of the lever in acquiring momentum.

Even such elaborately modified implements as the treadmill and the rowboat are operated on the principle of the lever. These also are mechanisms that have come down to us from a high antiquity. Their utility, however, has been greatly decreased in modern times, by the substitution of more elaborate and economical mechanisms for accomplishing their respective purposes. The treadmill, indeed—which might be likened to an overshot waterwheel in which the human foot supplied the place of the falling water in giving power—has become obsolete, though a modification of it, to be driven by animal power, is still sometimes used, as we shall see in a moment.

All these are illustrations of mechanisms with the aid of which human labor is made effective. They show the devices by which primitive man used his ingenuity in making his muscular system a more effective machine for the performance of work. But perhaps the most ingenious feat of all which our primitive ancestor accomplished was in learning to utilize the muscular energy of other animals. Of course the example was always before him in the observed activity of the animals on every side. Nevertheless, it was doubtless long before the idea suggested itself, and probably longer still before it was put into practise, of utilizing this almost inexhaustible natural supply of working energy.

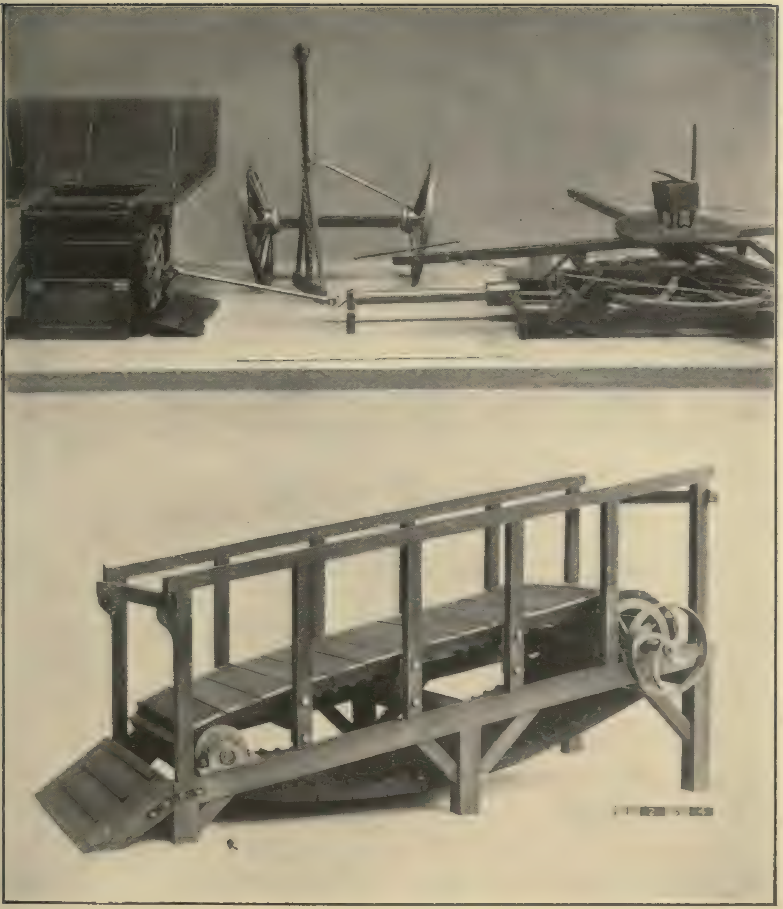
DOMESTICATED ANIMALS

The first animal domesticated is believed to have been the dog, and this animal is still used, as everyone knows, as a beast of burden in the far North, and in some European cities, particularly in those of Germany. Subsequently the ox was domesticated, but it is probable that for a vast period of time it was used for food purposes, rather than as a beast of burden. And lastly the horse, the worker *par excellence*, was made captive by some Asiatic tribes having the genius of invention, and in due course this fleetest of carriers and most efficient of draught animals was introduced into all civilized nations.

Doubtless for a long time the energy of the horse was utilized in an uneconomical way, through binding the burden on its back, or causing it to drag the burden along the ground. But this is inferential, since, as we have seen, the wheel was invented in pre-historic times, and at the dawn of history we find the Babylonians driving harnessed horses attached to wheeled vehicles. From that day to this the method of using horse-power has not greatly changed. The vast majority of the many millions of horses that are employed every day in helping on the world's work, use their strength without gain or loss through leverage, and with only the aid of rolling friction to increase their capacity as beasts of burden.

To a certain extent horse-power is still used with the aid of the modified treadmill just referred to—consisting essentially of an inclined plane of flexible mechanism made into an endless platform, which the horse causes to revolve as he goes through the movements of walking upon it. In agricultural districts this form of power is still sometimes used to run threshing machines, cider mills, wood-saws, and the like. Another application of horse-power to the same ends is accomplished through harnessing a horse to a long lever like the spoke of a wheel, fastened to an axis, which is made to revolve as the horse walks about it. Several horses are sometimes hitched to such a mechanism, which becomes then a wheel of several spokes. But this mechanism, which was common enough in agricultural districts two or three decades ago, has been practically superseded in recent years by the perambulatory steam engine.

It is obvious that the amount of work which a horse can accomplish must vary greatly with the size and quality of the horse, and with the particular method by which its energy is applied. For the purposes of comparison, however, an arbitrary amount of work has been fixed upon as constituting what is called a horse-power. This amount is the equivalent of raising



TWO APPARATUSES FOR THE UTILIZATION OF ANIMAL POWER

The upper figure shows the type of portable horse-power machine used for threshing grain in 1851. The lower figure is an inclined-plane horse-gear. The horse stands on the sloping platform tied to the bar in front, so that it is compelled to walk as the platform recedes.

thirty-three thousand pounds of weight to the height of one foot in one minute. It would be hard to say just why this particular standard was fixed upon, since it certainly represents more than the average capacity of a horse. It is, however, a standard which long usage (it was first suggested by Watt, of steam-engine fame) has rendered convenient, and one which the machinist refers to constantly in speaking of the efficiency of the various types of artificial machines. All questions of the exact legitimacy of this particular standard aside, it was highly appropriate that the labor of the horse, which has made up so large a share of the labor of the past, and which is still so extensively utilized, should continue to be taken as the measuring standard of the world's work.

IV

THE WORK OF AIR AND WATER

THE store of energy contained in the atmosphere and in the waters of the globe is inexhaustible. Its amount is beyond all calculation; or if it were vaguely calculated the figures would be quite incomprehensible from their very magnitude. It is not, however, an altogether simple matter to make this energy available for the purposes of useful work. We find that throughout antiquity comparatively little use was made of either wind or water in their application to machinery.

Doubtless the earliest use of air as a motive power was through the application of sails to boats. We know that the Phœnicians used a simple form of sail, and no doubt their example was followed by all the maritime peoples of subsequent periods. But the use of the sail even by the Phœnicians was as a comparatively unimportant accessory to the galaxies of oars, which formed the chief motive power. The elaboration of sails of various types, adequate in extent to propel large ships, and capable of being adjusted so as to take advantage of winds blowing from almost any quarter, was a development of the Middle Ages.

The possibilities of work with the aid of running water were also but little understood by the ancients. In the days of slave labor it was scarcely worth while to tax man's ingenuity to invent machines, since so efficient a one was provided by nature. Yet the properties of both air and water were studied by various mechanical philosophers, at the head of whom were Archimedes, whose work has already been referred to, and the famous Alexandrian, Ctesibius, whose investigations became familiar through the publications of his pupil, Hero.

Perhaps the most remarkable device invented by Ctesibius was a fire-engine, consisting of an arrangement of valves constituting a pump, and operating on the principle which is still in vogue. It is known, however, that the Egyptians of a much earlier period used buckets having valves in their bottoms, and these perhaps furnished the foundation for the idea of Ctesibius. It is unnecessary to give details of this fire-engine. It may be noted, however, that the principle of the lever is the one employed in its operation to gain power. A valve consists essentially of any simple hinged substance, arranged so that it may rise or fall, alternately opening and closing an aperture. A mere flap of leather, nailed on one edge, serves as a tolerably effective valve. At least one of the valves used by Ctesibius was a hinged piece of smooth metal. A piston fitted in a cylinder supplies suction when the lever is raised, and pressure when it is compressed, alternately opening the valve and closing the valve through which the water enters the tube. Meantime a second valve alternating with the first permits the water to enter the chamber containing air, which through its elasticity and pressure equalizes the force of the stream that is ejected from the chamber through the hose.

SUCTION AND PRESSURE

In the construction of this and various other apparatus, Ctesibius and Hero were led to make careful studies of the phenomena of suction. But in this they were not alone, since numerous of their predecessors had studied the subject, and such an apparatus as the surgeon's cupping glass was familiarly known several centuries before the Christian era. The cupping glass, as perhaps should be explained to the reader of the present day—since the apparatus went out of vogue in ordinary medical practise two or three generations ago—consists of a glass cup in which the air is exhausted, so as to suck blood from any part of the surface of a body to which it is applied. Hero describes a method of exhausting air by which such suction may be facilitated. But neither he nor any other philosopher of his period at all understood the real nature of this suction, notwithstanding their perfect familiarity with numerous of its phenomena. It was known, for example, that when a tube closed at one end is filled with water and inverted with the open end beneath the surface of the water, the water remains in the tube, although one might naturally expect that it would obey the impulses of gravitation and run out, leaving the tube empty. A familiar explanation of this and allied phenomena throughout antiquity was found in the saying that "Nature abhors a vacuum." This explanation, which of course amounts to no explanation at all, is fairly illustrative of the method of metaphysical word-juggling that served so largely among the earlier philosophers in explanation of the mysteries of physical science.

The real explanation of the phenomena of suction was not arrived at until the revival of learning in the seventeenth century. Then Torricelli, the pupil of Galileo, demonstrated that the word suction, as commonly applied, had no proper application; and that the phenomena hitherto ascribed to it were really due to the pressure of the atmosphere. A vacuum is merely an enclosed space deprived of air, and the "abhorrence" that Nature shows to such a space is due to the fact that air has weight and presses in every direction, and hence tends to invade every space to which it can gain access. It was presently discovered that if the inverted tube in which the water stands was made high enough, the water will no longer fill it, but will sink to a certain level. The height at which it will stand is about thirty feet; above that height a vacuum will be formed, which, for some reason, Nature seems not to abhor. The reason is that the weight of any given column of water about thirty feet in height is just balanced by the weight of a corresponding column of atmosphere. The experiments that gave the proof of this were made by the famous Englishman, Boyle. He showed that if the heavy liquid, mercury, is used in place of water, then the suspended column will be only about thirty inches in height. The weight or pressure of the atmosphere at sea level, as measured by these experiments, is about fifteen pounds to the square inch.

Boyle's further experiments with the air and with other gases developed the fact that the pressure exerted by any given quantity of gas is proportional to the external pressure to which it is subjected, which, after all, is only a special application of the law that action and reaction are equal. The further fact was developed that under pressure a gas decreases at a fixed rate in bulk. A general law, expressing these facts in the phrase that density and elasticity vary inversely with the pressure in a precise ratio, was developed by Boyle and the Frenchman, Mariotte, independently, and bears the name of both of its discoverers. No immediate application of the law to the practical purposes of the worker was made, however, and it is only in recent years that compressed air has been extensively employed as a motive power. Even now it has not proved a great commercial success, because other more economical methods of power production are available. In particular cases, however, it has a certain utility, as a relatively large available source of energy may be condensed into a very small receptacle.

A very striking experiment illustrating the pressure of the air was made by a famous contemporary of Boyle and Mariotte, by the name of Otto von Guericke. He connected an air pump with a large brass sphere, composed of two hemispheres, the edges of which fitted smoothly, but were not connected by any mechanism. Under ordinary conditions the hemispheres would fall apart readily, but von Guericke proved, by a famous public demonstration, that when the air was exhausted in the sphere, teams of horses pulling in opposite directions on the hemispheres could not separate them. This is famous as the experiment of the Magdeburg spheres, and it is often repeated on a smaller scale in the modern physical laboratory, to the astonishment of the tyro in physical experiments.

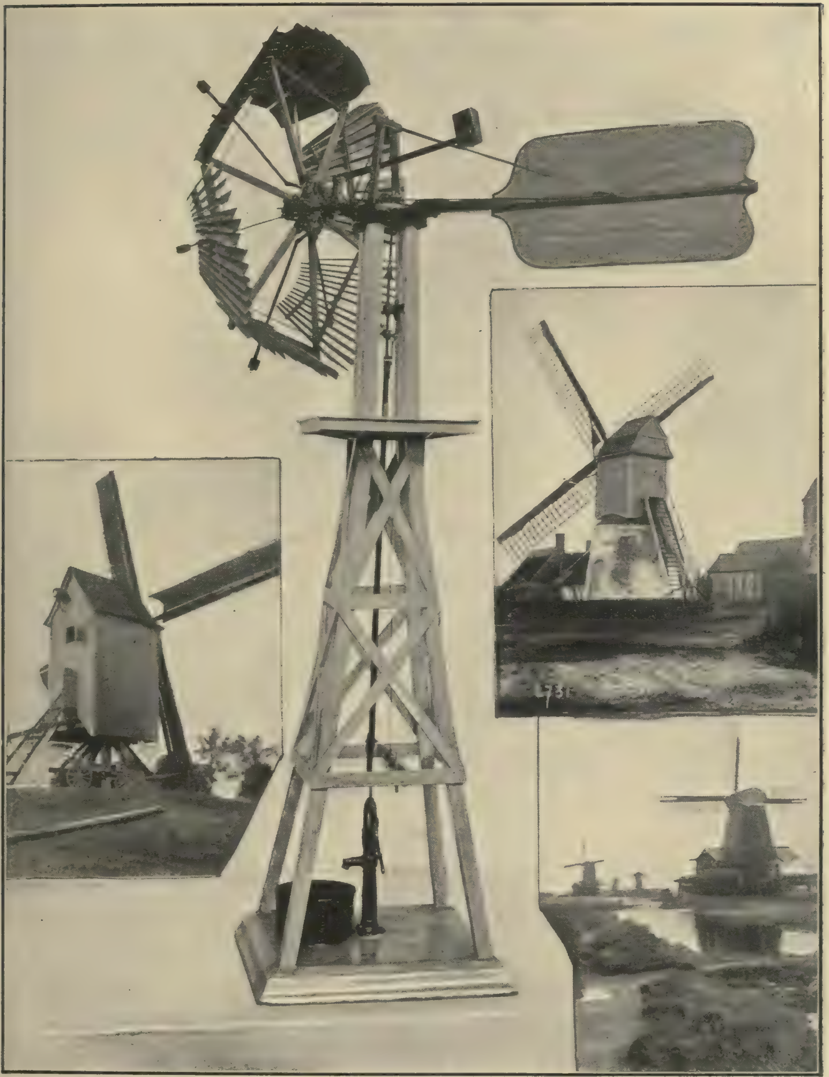
The first question that usually comes to the mind of anyone who has personally witnessed such an experiment, is the question as to how the human body can withstand the tremendous force to which it is subjected by an atmosphere exerting a pressure of fifteen pounds on every square inch of its surface. The explanation is found in the uniform distribution of the pressure, the influence of which is thus counteracted, and by the fact that the tissues themselves contain everywhere a certain amount of air at the same pressure. The familiar experiment of holding the hand over an exhausted glass cylinder—which experiment is indeed but a modification of the use of the cupping glass above referred to—illustrates very forcibly the insupportable difficulties which the human body would encounter were not its entire surface uniformly subjected to the atmospheric pressure.

AIR IN MOTION

At about the time when the scientific experiments with the pressure of gases were being made, practical studies of the effects of masses of air in motion were undertaken by the Dutch philosopher, Servinus. The use of the windmill in Holland as a means of generating power doubtless suggested to Servinus the possibility of attaching a sail to a land vehicle. He made the experiment, and in the year 1600 constructed a sailing car which, propelled by the wind, traversed the land to a considerable distance, on one occasion conveying a company of which Prince Maurice of Orange was a member. But his experiments have seldom been repeated, and indeed their lack of practical feasibility scarcely needs demonstration.

The utility of the wind, however, in generating the power in a stationary mechanism is familiar to everyone. Windmills were constructed at a comparatively early period, and notwithstanding all the recent progress in the development of steam and electrical power, this relatively primitive so-called prime mover still holds its own in agricultural districts, particularly in its application to pumps. A windmill consists of a series of inclined planes, each of which forms one of the radii of a circle, or spokes of a wheel, to the axle of which a gearing is adjusted by which the power generated is utilized. The wheel is made to face the wind by the wind itself blowing against a sort of rudder which projects from the axis. The wind blowing against the inclined surfaces or vanes of the wheel causes each vane to move in accordance with the law of component forces, thus revolving the wheel as a whole.

It has been affirmed that the Romans had windmills, but "the silence of Vitruvius, Seneca, and Chrysostom, who have spoken of the advantages of the wind, makes



WINDMILLS OF ANCIENT AND MODERN TYPES.

The smaller figures show Dutch windmills of the present day, many of which are identical in structure with the windmills of the middle ages. It will be seen that the sails can be furled when desired to put the mill out of operation. In the mill of modern type (large figure) the same effect is produced by slanting the slats of the wheel.

this opinion questionable." It has been supposed by other writers that windmills were used in France in the sixth century, while still others have maintained that this mechanism was unknown in Europe until the time of the Crusades. All that is tolerably certain is that in the twelfth century windmills were in use in France and England. It is recorded that when they began to be somewhat common Pope Celestine III. determined that the tithes of them belonged to the clergy.

INHERENT DEFECTS OF THE WINDMILL

The mediæval European windmill was supplied with great sails of cloth, and its picturesque appearance has been made familiar to everyone through the famous tale of *Don Quixote*. The modern windmill, acting on precisely the same principle, is a comparatively small affair, comprising many vanes of metal, and constituting a far more practical machine. The great defect of all windmills, however, is found in the fact that of necessity they furnish such variable power, since the force of the wind is incessantly changing. Worst of all, there may be protracted periods of atmospheric calm, during which, of course, the windmill ceases to have any utility whatever. This uneradicable defect relegates the windmill to a subordinate place among prime movers, yet on the other hand, its cheapness insures its employment for a long time to come, and the industry of manufacturing windmills continues to be an important one, particularly in the United States.

RUNNING WATER

The aggregate amount of work accomplished with the aid of the wind is but trifling, compared with that which is accomplished with the aid of water. The supply of water is practically inexhaustible, and this fluid being much more manageable than air, can be made a far more dependable aid to the worker. Every stream, whatever its rate of flow, represents an enormous store of potential energy. A cubic foot of water weighs about sixty-two and a half pounds. The working capacity of any mass of water is represented by one-half its weight into the square of its velocity; or, stated otherwise, by its weight into the distance of its fall. Now, since the interiors of the continents, where rivers find their sources, are often elevated by some hundreds or even thousands of feet, it follows that the working energy expended—and for the most part wasted—by the aggregate water current of the world is beyond all calculation. Meantime, however, a portion of the energy which in the aggregate represents an enormous working power is utilized with the aid of various types of water wheels.

Watermills appear to have been introduced in the time of Mithridates, Julius Cæsar, and Cicero. Strabo informs us that there was a watermill near the residence of Mithridates; and we learn from Pomponius Sabinus, that the first mill seen at Rome was erected on the Tiber, a little before the time of Augustus. That they existed in the time of Augustus is obvious from the description given of them by Vitruvius, and the epigram of Antipater, who is supposed to have lived in the time of Cicero. But though mills driven by water were introduced at this early period, yet public mills did not appear till the time of Honorius and Arcadius. They were erected on three canals, which conveyed water to the city, and the greater number of them lay under Mount Janiculum. When the Goths besieged Rome in 536, and stopped the large aqueduct and consequently the mills, Belisarius appears to have constructed, for the first time, floating mills upon the Tiber. Mills driven by the tide existed at Venice in the year 1046, or at least in 1078.

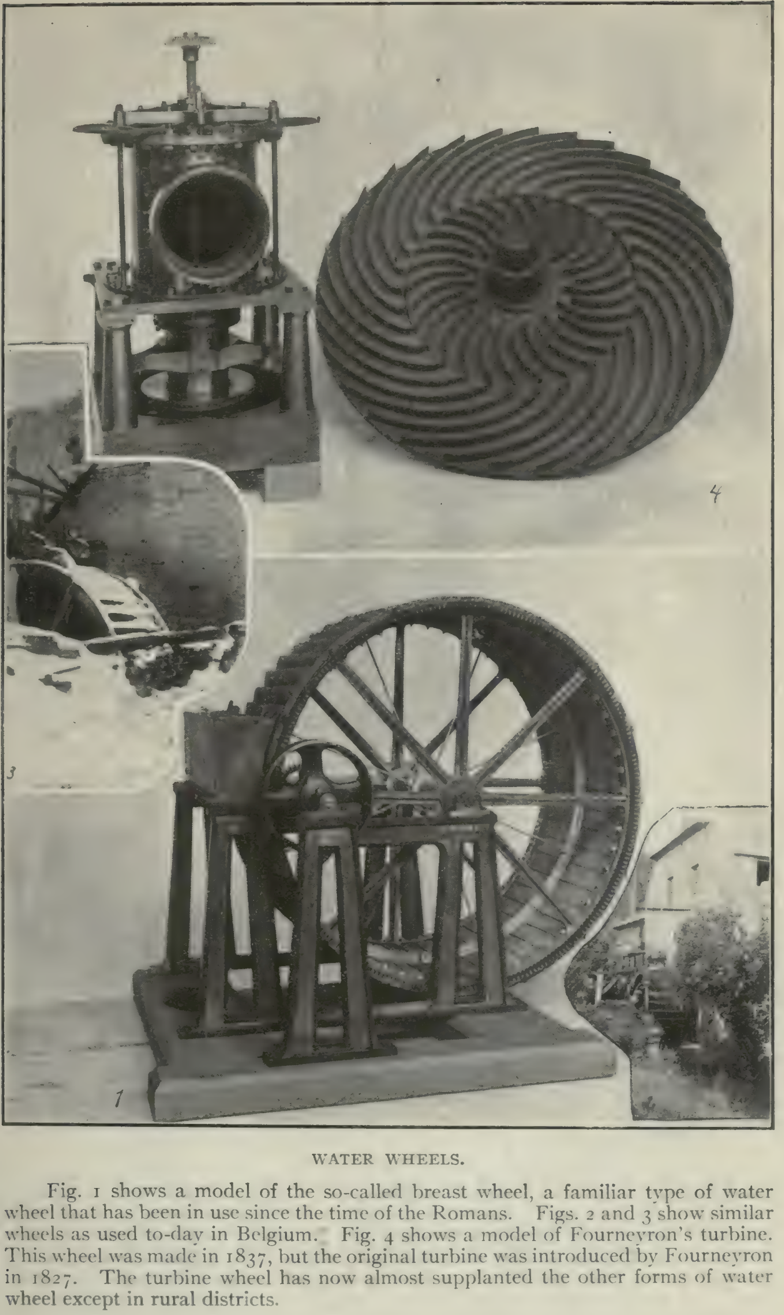
The older types of water wheel are exceedingly simple in construction, consisting merely of vertical wheels revolving on horizontal axes, and so placed as to receive the weight or pressure of the water on paddles or buckets at their circumference. The water might be allowed to rush under the wheel, thus constituting an under-shot wheel; or more commonly it flows from above, constituting an over-shot wheel. Where the natural fall is not available, dams are employed to supply an artificial fall.

This primitive type of water wheel has been practically abandoned within the last generation, its place having been taken by the much more efficient type of wheel known as the turbine. This consists of a wheel, usually adjusted on a vertical axis, and acting on what is virtually the principle of a windmill. To gain a mental picture of the turbine in its simplest form, one might imagine the propelling screw of a steamship, placed horizontally in a tube, so that the water could rush against its blades. The tiny windmills which children often make by twisting pieces of paper illustrate the same principle. Of course, in its developed form the turbine is somewhat elaborated, in the aim to utilize as large a proportion of the energy of the falling water as is possible ; but the principle remains the same.

The turbine wheel was invented by a Frenchman named Fourneyron, about three-quarters of a century ago (1827), but its great popularity, in America in particular, is a matter of the last twenty or thirty years. To-day it has virtually supplanted every other type of water wheel. To use any other is indeed a wasteful extravagance, as the perfected turbine makes available more than eighty per cent. of the kinetic energy of any mass of falling water. A turbine wheel two feet in diameter is able to do the work of an enormous wheel of the old type.

Turbine wheels are of several types, one operating in a closed tube to which air has no access, and another in an open space in the presence of air. The water may also be made to enter the turbine at the side or from below, thus serving to support the weight of the mechanism—a consideration of great importance in the case of such gigantic turbines as those that are employed at Niagara Falls, which we shall have occasion to examine in detail in a later chapter.

The power generated by a revolution of the turbine wheel may, of course, be utilized directly by belts or gearings attached to its axle, or it may be transferred to a distance, with the aid of a dynamo generating electricity. The latter possibility, which has only re-



WATER WHEELS.

Fig. 1 shows a model of the so-called breast wheel, a familiar type of water wheel that has been in use since the time of the Romans. Figs. 2 and 3 show similar wheels as used to-day in Belgium. Fig. 4 shows a model of Fourneyron's turbine. This wheel was made in 1837, but the original turbine was introduced by Fourneyron in 1827. The turbine wheel has now almost supplanted the other forms of water wheel except in rural districts.

cently been developed, and which we shall have occasion to examine in detail in connection with our studies of the power at Niagara, gives a new field of usefulness to the turbine wheel, and makes it probable that this form of power will be vastly more used in the future than it has been in the past. Indeed, it would not be surprising were it ultimately to become the prime source of working energy as utilized in every department of the world's work.

Mr. Edward H. Sanborn, in an article on Motive Power Appliances in the Twelfth Census Report of the United States, comments upon the recent advances in the use of water wheels as follows:

"One notable advance in turbine construction has been the production of a type of wheel especially designed for operating under much higher heads of water than were formerly considered feasible for wheels of this type. Turbines are now built for heads ranging from 100 to 1,200 feet, and quite a number of wheels are in operation under heads of from 100 to 200 feet. This is an encroachment upon the field occupied almost exclusively by wheels variously known as the 'impulse,' 'impact,' 'tangential,' or 'jet' type, the principle of which is the impact of a powerful jet of water from a small nozzle upon a series of buckets mounted upon the periphery of a small wheel."

"The impact water wheel," Mr. Sanborn continues, "has come largely into use during the last ten years, principally in the far West, where higher heads of water are available than can be found in other parts of the country. With wheels of this type, exceedingly simple in construction and of comparatively small cost, a large amount of power is developed with great economy under the great heads that are available. With the tremendous water pressure developed by heads of 1,000 feet and upward, which in many cases are used for this purpose, wheels of small diameter develop an extraordinary amount of power. To the original type of impact wheel which first led the field have been added several styles embodying practically the same principle. Considerable study has been given to the designing of buckets with a view to securing free discharge and the avoidance of any disturbing eddies, and important improvements have resulted from the thorough investigation of the action of the water during, and subsequent to, its impact on the buckets. The impact wheel has been adapted to a wide range of service with great variation as to the conditions under which it operates, wheels having been made in California from 30 inches to 30 feet in diameter, and to work under heads ranging from 35 to 2,100 feet, and at speeds ranging from 65 to 1,100 revolutions per minute. A number of wheels of this type have been built with capacities of not less than 1,000 horse-power each."

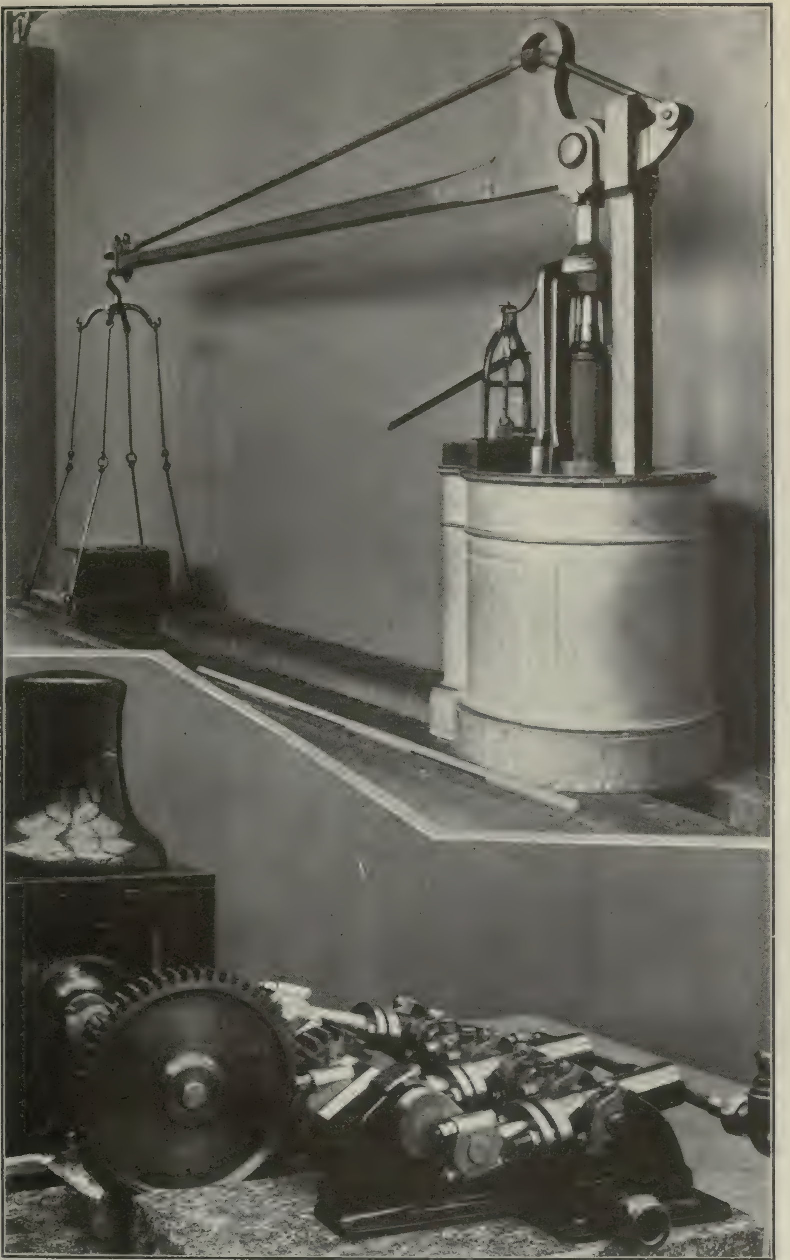
HYDRAULIC POWER

A few words should be said about the familiar method of transmitting power with the aid of water, as illustrated by the hydrostatic press. This does not indeed utilize the energy of the water itself, but it enables the worker to transmit energy supplied from without, and to gain an indefinite power to move weights through a short distance, with the expenditure of very little working energy. The principle on which the hydrostatic press is based is the one which was familiar to the ancient philosophers under the name of the hydrostatic paradox. It was observed that if a tube is connected with a closed receptacle, such as a strong cask, and cask and tube are filled with water, the cask will presently be burst by the pressure of the water, provided the tube is raised to a height, even though the actual weight of water in the tube be comparatively slight. A powerful cask, for example, may be burst by the water poured into a slender pipe. The result seems indeed paradoxical, and for a long time no explanation of it was forthcoming. It remained for Servinus, whose horseless wagon is elsewhere noticed, to discover that the water at any given level presses equally in all directions, and that its pressure is proportionate to its depth, quite regardless of its bulk. Then, supposing the tube in our experiment to have a cross-section of one square inch, a pressure equal to that in the tube would be transmitted to each square inch of the surface of the cask; and the pressure might thus become enormous.

If, instead of a tube lifted to a height, the same tube is connected with a force pump operated with a lever—an apparatus similar to the fire-engine of Ctesibius—it is obvious that precisely the same effect may be produced; whatever pressure is developed in the piston of the force pump, similar pressure will be transferred to a corresponding area in the surface of the cask or receptacle with which the force pump connects. In practise this principle is utilized, where great pressure is desired, by making a receptacle with an enormous piston connecting with the force pump just described.

An indefinite power may thus be developed, the apparatus constituting virtually a gigantic lever. But the principle of the equivalence of weight and distance still holds, precisely as in an actual lever, and while the pressure that may be exerted with slight expenditure of energy is enormous, the distance through which this pressure acts is correspondingly small. If, for example, the piston of the force pump has an area of one square inch, while the piston of the press has an area of several square feet, the pressure exerted will be measured in tons, but the distance through which it is exerted will be almost infinitesimal. The range of utility of the hydrostatic press is, therefore, limited, but within its sphere, it is an incomparable transmitter of energy.

Moreover, it is possible to reverse the action of the hydraulic apparatus so as to gain motion at the expense of power. A familiar type of elevator is a case in point. The essential feature of the hydraulic elevator consists of a ram attached to the bottom of the elevator and extending down into a cylinder, slightly longer than the height to which the elevator is to rise. The ram is fitting into a cylinder with water-tight packing, or a cut leather valve. Water under high pressure is admitted to the cylinder through the valve at the bottom, and the pressure thus supplied pushes up the ram, carrying the elevator with it, of course. Another valve allows the water to escape, so that ram and elevator may descend, too rapid descent being prevented by



HYDRAULIC PRESS AND HYDRAULIC CAPSTAN.

The upper figure shows Bramah's original hydraulic pump and press, now preserved in the South Kensington Museum, London. The machine was constructed in 1796 by Joseph Bramah to demonstrate the principle of his hydraulic press. The discrepancy in size between the small lever worked by hand and the enormous lever carrying a heavy weight gives a vivid impression of the gain in power through the use of the apparatus. The lower figure shows the hydraulic capstan used on many modern ships, in which the same principle is utilized.

the partial balancing of ram and elevator with weights acting over pulleys. The ram, to the end of which pressure is thus applied, need be but a few inches in diameter. Water pressure is secured by bringing water from an elevation. Such an elevator acts slowly, but is a very safe and in many ways satisfactory mechanism. Such elevators are still used extensively in Europe, but have been almost altogether displaced in America by the electric elevator.

The hydraulic elevator just described is virtually a water engine, the ram acting as piston. A veritable engine, of small size, to perform any species of mechanical work, may be constructed on precisely the same principle, the piston in this case acting in a cylinder similar to that of the ordinary steam engine. Such an engine operates slowly but with great power. It has special utility where it is desirable to apply power intermittently, as in various parts of a dockyard, or in handling guns and ammunition on shipboard. In the former case in particular, it is often inconvenient to use steam power, as steam sent from a central boiler condenses in a way to interfere with its operation. In such a case any number of small water-pressure engines may be operated from a single tank where water is at a high elevation, or where the requisite pressure is secured artificially. In the latter case, the water is kept under pressure by a large piston or ram heavily weighted, the entire receptacle being, of course, of water-tight construction and adapted to withstand pressure. The pump that supplies the tank is ordinarily made to work automatically, ceasing operation as soon as the ram rises to the top of the receptacle, and beginning again whenever, through use of water, the ram begins to descend. Such an apparatus is called an accumulator. Such water engines have come into vogue only in comparatively recent times, being suggested by the steam engine. As already pointed out, their utility is restricted, yet the total number of them in actual use today is large, and their share in the world's work is not altogether inconsiderable.

V

CAPTIVE MOLECULES: THE STORY OF THE STEAM ENGINE

WE come now to that all-important transformer of power, the steam engine. Everybody knows that steam is a state of water in which, under the influence of heat, the molecules have broken away from the mutual attraction of cohesion, and are flying about at inconceivable speed, rebounding from one another after collision, in virtue of their elasticity, exerting in the aggregate an enormous pressure in every direction. It is this consideration of the intimate character of steam that justifies the title of the present chapter; a title that has further utility as drawing a contrast between the manner of working with which we are now to be concerned, and the various types of workers that we have previously considered.

In speaking of the animal machine and of work accomplished by the air and the water, we have been concerned primarily with masses of matter, possessing and transmitting energy. Of course molecules—since they make up the substance of all matter—could not be altogether ignored, but in the main we have had to do with molar rather than with molecular motion. Now, however, we are concerned with a mechanism in which the molecular activities are directly concerned in performing work.

Even in the aggregate the molecules make up a mere intangible gas, which requires to be closely confined in order that its energy may be made available. Once the molecules have performed their work, they are so changed in their activities that they sink back, as it were, exhausted, into a relatively quiescent state, which enables their latent cohesive forces to reduce them again to the state of a liquid. In a word, we are concerned with the manifestation of energy which depends upon molecular activities in a way quite different from what has been the case with any of the previously considered mechanisms. The tangible manifestation of energy which we term heat is not merely a condition of action and a by-product, as it was in the case of the animal machine; it is the essential factor upon which all the efficiency of the mechanism depends.

It should perhaps be stated that this explanation of the action of the steam engine is a comparatively modern scientific interpretation. The earlier experimenters brought the steam engine to a high state of efficiency, without having any such conception as this of the nature of steam itself. For practical purposes it suffices to note that water when heated takes the form of steam; that this steam has the property of powerful and indefinite expansion; and thirdly, that when allowed to escape from a state of pressure, sudden expansion of the steam cools it sufficiently to cause the recondensation of part of its substance, thus creating a vacuum.

Stated in few words, the entire action of the steam depends upon these simple mechanical principles. The principles are practically applied by permitting the steam to enter the cylinder where it can act on a piston, to which it gives the thrust that is transmitted to an external mechanism by means of a rod attached to the piston. When the piston has been driven to the end of the desired thrust, the valve is opened automatically, permitting the steam to escape, thus producing a vacuum, and insuring the return thrust of the piston, which is further facilitated, ordinarily, by the admission of steam to the other side of the piston. Practical operation of this mechanism is familiar to everyone, though the marvel of its power and efficiency seems none the less because of its familiarity.

It is not too much to say that this relatively simple device, in its first general application, marked one of the most important turning points in the history of civilization. To its influence, more than to any other single cause, must be ascribed the revolutionary change that came over the character of practical life in the nineteenth century. From prehistoric times till well toward the close of the eighteenth century, there was scarcely any important change in carrying out the world's work. And in the few generations that have since elapsed, the entire aspect of the mechanical world has been changed, the working efficiency of the individual has been largely increased; mechanical tasks have become easy which hitherto were scarcely within the range of human capacity.

Before we go on to the detailed study of the machine which has produced these remarkable results, it is desirable to make inquiry as to the historical development of so important an invention.

The practical steam engine in its modern form dates, as just mentioned, from the latter part of the eighteenth century, and was perfected by James Watt, who is commonly thought of as being its inventor. In point of fact, however, the history of most inventions is duplicated here, as on examination it appears that various forerunners of Watt had been on the track of the steam engine, and some of them, indeed, had produced a workable machine of no small degree of efficiency.

The very earliest experiments were made away back in the Alexandrian days in the second century before the Christian era, the experimenter being the famous Hero, whose work in an allied field was referred to in the preceding chapter. Hero produced—or at least described and so is credited with producing, though the actual inventor may have been Ctesibius—a little toy mechanism, in which a hollow ball was made to revolve on an axis through the agency of steam, which escaped from two bent tubes placed on opposite sides of the ball, their orifices pointing in opposite directions. The apparatus had no practical utility, but it sufficed to establish the principle that heat, acting through the agency of steam, could be made to do mechanical work. Had not the age of Hero been a time of mental stasis, it is highly probable that the principle he had thus demonstrated would have been applied to some more practical mechanism in succeeding generations. As it was, however, nothing practical came of his experiment, and the steam turbine engine was remembered only as a scientific toy.

No other worker continued the experiments, so far as is known, until the time of the great Italian, Leonardo da Vinci, who, late in the fifteenth century, gave a new impulse to mechanical invention. Leonardo experimented with steam, and succeeded in producing what was virtually an explosion engine, by the agency of which a ball was propelled along the earth. But this experiment also failed to have practical result.

BEGINNINGS OF MODERN DISCOVERY

Such sporadic experiments as these have no sequential connection with the story of the evolution of the steam engine. The experiments which led directly on to practical achievements were not begun until the seventeenth century. In the very first year of that century, an Italian named Giovanni Battista della Porta published a treatise on pneumatics, in which the idea of utilizing steam for the practical purpose of raising water was expressly stated. The idea of this inventor was put into effect in 1624 by a French engineer and mathematician, Solomon de Caus. He invented two different machines, the first of which required a spherical boiler having an internal tube reaching nearly to the bottom; a fire beneath the boiler produced steam which would force the water in the boiler to a height proportional to the pressure obtained. In the other machine, steam is led from the boiler into the upper part of a closed cistern containing water to be elevated. To the lower portion of the cistern a delivery pipe was attached so that water was discharged under a considerable pressure. This arrangement was precisely similar to the apparatus employed by Hero of Alexandria in various of his fountains, as regards the principle of expanding gas to propel water. An important difference, however, consists in the fact that the scheme of della Porta and of de Caus embodied the idea of generating pressure with the aid of steam, whereas Hero had depended merely on the expansive property of air compressed by the water itself.

While these mechanisms contained the germ of an idea of vast importance, the mechanisms themselves were of trivial utility. It is not even clear whether their projectors had an idea of the properties of the condensation of vapor, upon which the working of the practical steam engine so largely depends. This idea, however, was probably grasped about half a century later by an Englishman, Edward Somerset, the celebrated Marquis of Worcester, who in 1663 described in his *Century of Inventions* an apparatus for raising water by the expansive force of steam. His own account of his invention is as follows:

"An admirable and most forcible way to drive up water by fire; not by drawing or sucking it upwards, for that must be as the philosopher calleth it, *intra sphæram activitatis*, which is but at such a distance. But this way hath no bounder, if the vessel be strong enough: for I have taken a piece of whole cannon, whereof the end was burst, and filled it three-quarters full of water, stopping and screwing up the broken end, as also the touch-hole; and making a constant fire under it, within twenty-four hours it burst and made a great crack; so that having a way to make my vessels so that they are strengthened by the force within them, and the one to fill after the other, I have seen the water run like a constant stream, forty feet high: one vessel of water, rarefied by fire, driveth up forty of cold water; and the man that tends the work is but to turn two cocks, that one vessel of water being consumed, another begins to force and refill with cold water, and so successively; the fire being tended and kept constant, which the self-same person may likewise abundantly perform in the interim, between the necessity of turning the said cocks."

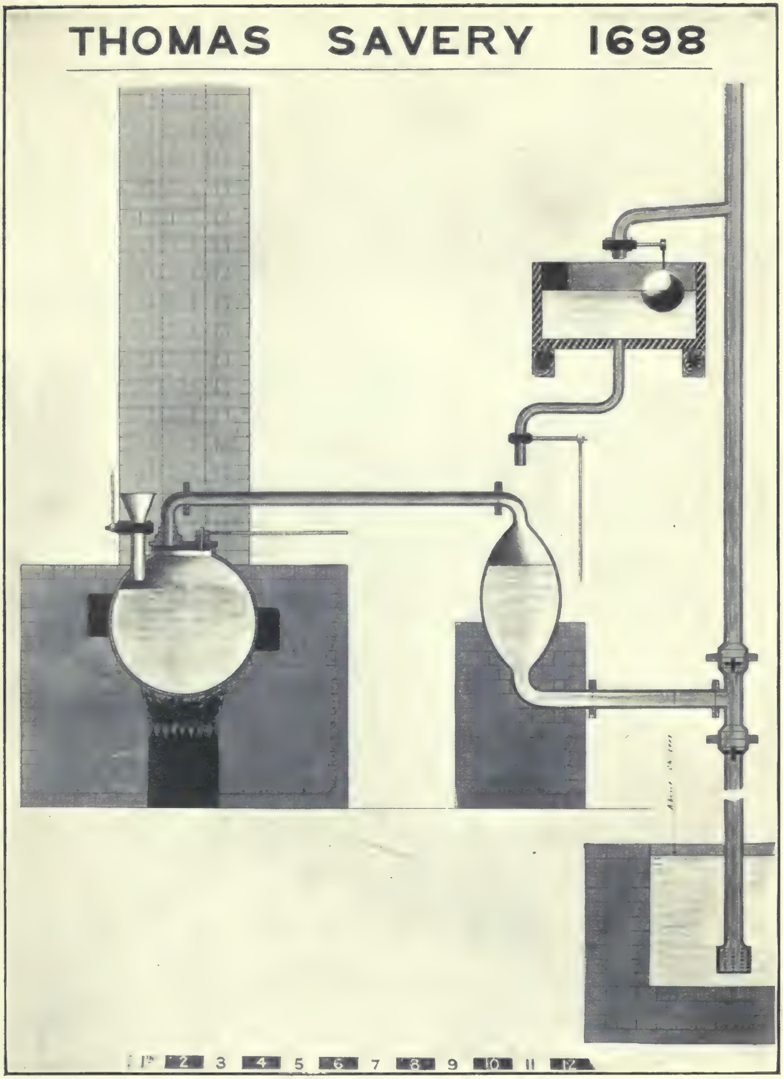
It is unfortunate that the Marquis did not give a more elaborate description of this remarkable contrivance. The fact that he treats it so casually is sufficient evidence that he had no conception of the possibilities of the mechanism; but, on the other hand, his description suffices to prove that he had gained a clear notion of, and had experimentally demonstrated, the tremendous power of expansion that resides in steam. No example of his steam pump has been preserved, and historians of the subject have been left in doubt as to some details of its construction, and in particular as to whether it utilized the principle of a vacuum created through condensation of the steam.

THOMAS SAVERY'S STEAM PUMP

This principle was clearly grasped, however, by another Englishman, Thomas Savery, a Cornish mine captain, who in 1698 secured a patent for a steam engine to be applied to the raising of water, etc. A working model of this machine was produced before the Royal Society in 1699. The transactions of the Society contain the following: "June 14th, 1699, Mr. Savery entertained the Royal Society with showing a small model of his engine for raising water by help of fire, which he set to work before them: the experiment succeeded according to expectation, and to their satisfaction."

The following very clear description of Savery's engine is given in the introduction to Beckmann's *History of Inventions:*

"This engine, which was used for some time to a considerable extent for raising water from mines, consisted of a strong iron vessel shaped like an egg, with a tube or pipe at the bottom, which descended to the place from which the water was to be drawn, and another at the top, which ascended to the place to which it was to be elevated. This oval vessel was filled with steam supplied from a boiler, by which the atmospheric air was first blown out of it. When the air was thus expelled and nothing but pure steam left in the vessel, the communication with the boiler was cut off, and cold water poured on the external surface. The steam within was thus condensed and a vacuum produced, and the water drawn up from below in the usual way by suction. The oval vessel was thus filled with water; a cock placed at the bottom of the lower pipe was then closed, and steam was introduced from the boiler into the oval vessel above the surface of the water. This steam being of high pressure, forced the water up the ascending tube, from the top of which it was discharged, and the oval vessel being thus refilled with steam, the vacuum was again


THOMAS SAVERY 1698
About 14 feet
1 ft
2
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THOMAS SAVERY'S STEAM ENGINE.

The principle involved is that of the expansion of steam exerting a propulsive force and its subsequent condensation to produce a vacuum. These are the principles employed in the modern steam engine, but the only use to which they were put in Savery's engine was the elevation of water by suction.

produced by condensation, and the same process was repeated. By using two oval steam vessels, which would act alternately—one drawing water from below, while the other was forcing it upwards, an uninterrupted discharge of water was produced. Owing to the danger of explosion, from the high pressure of the steam which was used, and from the enormous waste of heat by unnecessary condensation, these engines soon fell into disuse."

This description makes it obvious that Savery had the clearest conception of the production of a vacuum by the condensation of steam, and of the utilization of the suction thus established (which suction, as we know, is really due to the pressure of outside air) to accomplish useful work. Savery also arranged this apparatus in duplicate, so that one vessel was filling with water while the other was forcing water to the delivery pipe. This is credited with being the first useful apparatus for raising water by the combustion of fuel. There was a great waste of steam, through imparting heat to the water, but the feasibility of the all-important principle of accomplishing mechanical labor with the aid of heat was at last demonstrated.

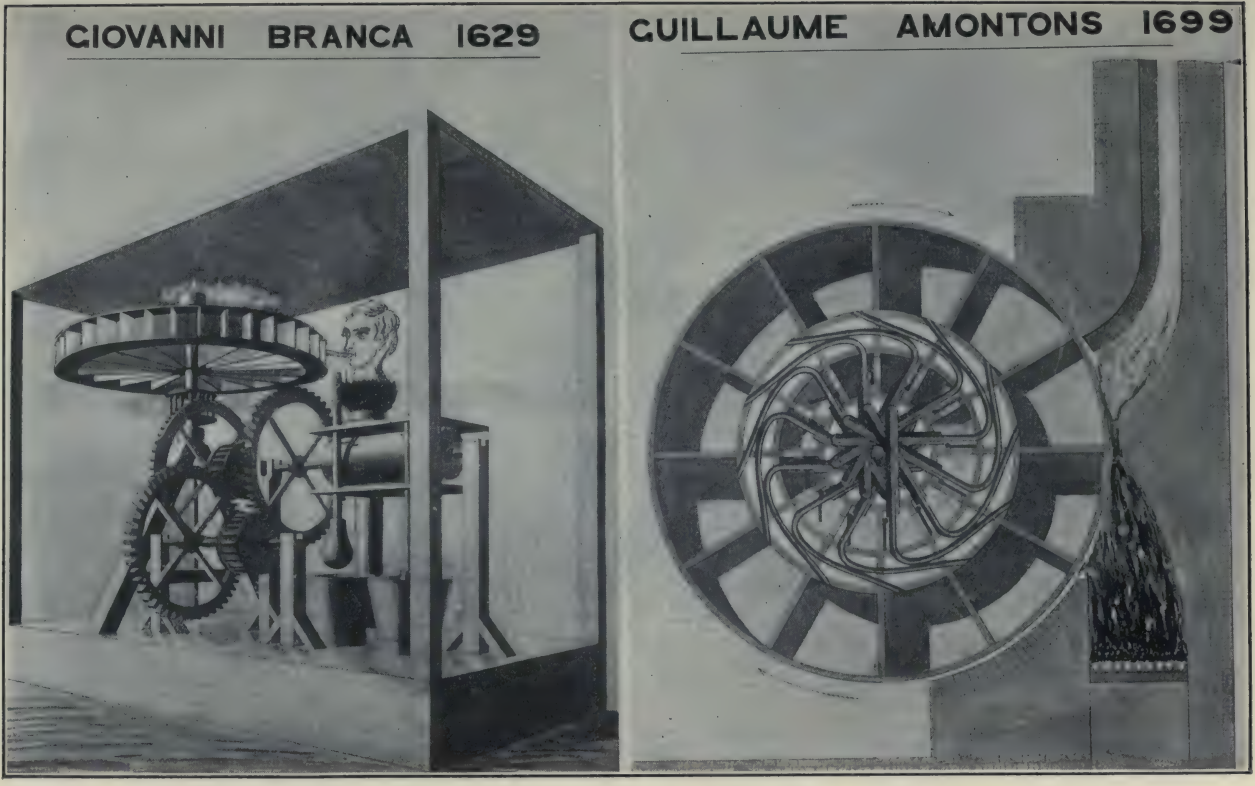
As yet, however, the experimenters were not on the track of the method by which power could be advantageously transferred to outside machinery. An effort in quite another direction to accomplish this had been made as early as 1629 by Giovanni Branca, an Italian mathematician, who had proposed to obtain rotary motion by allowing a jet of steam to blow against the vanes of a fan wheel, capable of turning on an axis.

In other words, he endeavored to utilize the principle of the windmill, the steam taking the place of moving air. The idea is of course perfectly feasible, being indeed virtually that which is employed in the modern steam turbine; but to put the idea into practise requires special detailed arrangements of steam jet and vanes, which it is not strange the early inventor failed to discover. His experiments appear not to have been followed up by any immediate successor, and nothing practical came of them, nor was the principle which he had attempted to utilize made available until long after a form of steam engine utilizing another principle for the transmission of power had been perfected.

DENIS PAPIN INVENTS THE PISTON ENGINE

The principle in question was that of causing expanding steam to press against a piston working tightly in a cylinder, a principle, in short, with which everyone is familiar nowadays through its utilization in the ordinary steam engine. The idea of making use of such a piston appears to have originated with a Frenchman, Denis Papin, a scientific worker, who, being banished from his own country, was established as professor of mathematics at the University of Marburg. He conceived the important idea of transmitting power by means of a piston as early as 1688, and about two years later added the idea of producing a vacuum in a cylinder, by cooling the cylinder,—the latter idea being, as we have just seen, the one which Savery put into effect.

It will be noted that Papin's invention antedated that


GIOVANNI BRANCA 1629
GUILLAUME AMONTONS 1699

DIAGRAMS OF EARLY ATTEMPTS TO UTILIZE THE POWER OF STEAM.

Two attempts to give rotation to a mechanical apparatus through the action of heated air or steam. Nothing practical came of either effort, but the mechanisms depicted are of historical interest.

of Savery; to the Frenchman, therefore, must be given the credit of hitting upon two important principles which made feasible the modern steam engine. Papin constructed a model consisting of a small cylinder in which a solid piston worked. In the cylinder beneath the piston was placed a small quantity of water, which, when the cylinder was heated, was turned into steam, the elastic force of which raised the piston. The cylinder was then cooled by removing the fire, when the steam condensed, thus creating a vacuum in the cylinder, into which the piston was forced by the pressure of the atmosphere.

Such an apparatus seems crude enough, yet it incorporates the essential principles, and required but the use of ingenuity in elaborating details of the mechanism, to make a really efficient steam engine. It would appear, however, that Papin was chiefly interested in the theoretical, rather than in the really practical side of the question, and there is no evidence of his having produced a working machine of practical power, until after such machines worked by steam had been constructed elsewhere.

THOMAS NEWCOMEN'S IMPROVED ENGINE

As has happened so often in other fields, Englishmen were the first to make practical use of the new ideas. In 1705 Thomas Newcomen, a blacksmith or ironmonger, and John Cawley, a plumber and glazier, patented their atmospheric engine, and five years later, in the year 1710, namely, Newcomen had on the market an engine which is described in the *Report of the Department of Science and Arts of the South Kensington Museum*, as "the first real pumping engine ever made."

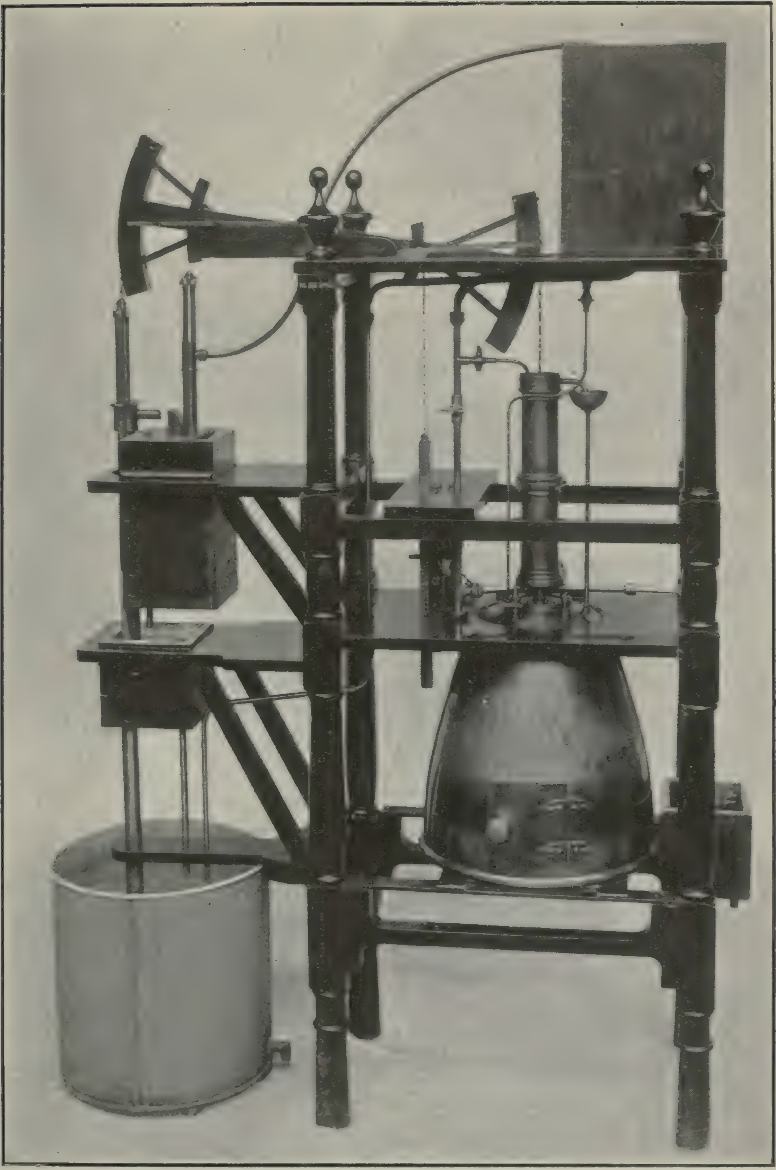
The same report describes the engine as "a vertical steam cylinder provided with a piston connected at one end of the beam, having a pivot or bearing in the middle of its length, and at the other end of the beam pump rods for working the pump. The cylinder was surrounded by a second cylinder or jacket, open at the top, and cold water could be supplied to this outer cylinder at pleasure. The single or working cylinder could be supplied with steam when desired from a boiler below it. There was a drain pipe from the bottom of the working cylinder, and one from the outer cylinder. For the working of the engine steam was admitted to the working cylinder, so as to fill it and expel all the air, the piston then being at the top, owing to the weight of the pump rods being sufficient to lift it; then the steam was shut off and the drain cocks closed and cold water admitted to the outer cylinder, so that the steam in the working cylinder condensed, and, leaving a partial vacuum of pressure of the atmosphere, forced the piston down and drew up the pump rods, thus making a stroke of the pump. Then the water was drawn off from the outer cylinder and steam admitted to the working cylinder before allowing the piston to return to the top of its stroke, ready for the next down stroke."

It will be observed that this machine adopts the principle, with only a change of mechanical details, of the Papin engine just described. A later improvement made by Newcomen did away with the outer cylinder for condensing the steam, employing instead an injection of cold water into the working cylinder itself, thus enabling the engine to work more quickly. It is said that the superiority of the internal condensing arrangement was accidentally discovered through the improved working of an engine that chanced to have an exceptionally leaky piston or cylinder. Many engines were made on this plan and put into practical use.

Another important improvement was made by a connection from the beam to the cocks or valves, so that the engine worked automatically, whereas in the first place it had been necessary to have a boy or man operate the valves,—a most awkward arrangement, in the light of modern improvements. As the story is told, the duty of opening and closing the regulating and condensing valves was intrusted to boys called cock boys. It is said that one of these boys named Humphrey Potter "wishing to join his comrades at play without exposing himself to the consequences of suspending the performance of the engine, contrived, by attaching strings of proper length to the levers which governed the two cocks, to connect them with the beam, so that it should open and close the cocks as it moved up and down with the most perfect regularity."

This story has passed current for almost two centuries, and it has been used to point many a useful moral. It seems almost a pity to disturb so interesting a tradition, yet it must have occurred to more than one iconoclast that the tale is almost too good to be true. And somewhat recently it has been more than hinted that Desaguliers, with whom the story originated, drew upon his imagination for it. A print is in existence, made so long ago as 1719, representing an engine erected by Newcomen at Dudley Castle, Staffordshire, in 1712, in which an automatic valve gear is clearly shown, proving that the Newcomen engine was worked automatically at this early period. That the admirable story of the inventive youth, whose wits gave him leisure for play, may not be altogether discredited, however, it should be added that unquestionably some of the early engines had a hand-moved gear, and that at least one such was still working in England after the middle of the nineteenth century. It seems probable, then, that the very first engines were without the automatic valve gear, and there is no inherent reason why a quick-witted youth may not have been the first to discover and remedy the defect.

According to the Report of the Department of Science and Arts of the South Kensington Museum: "The adoption of Newcomen's engine was rapid, for, commencing in 1711 with the engine at Wolverhampton, of twenty-three inch diameter and six foot stroke, they were in common use in English collieries in 1725; and Smeaton found in 1767 that, in the neighborhood of Newcastle alone there were fifty-seven at work, ranging in size from twenty-eight inch to seventy-five inch cylinder diameter, and giving collectively about twelve hundred horse-power. As Newcomen obtained an evaporation of nearly eight pounds of water per pound of coal, the increase of boiler efficiency since his time has necessarily been but slight, although in other requisites of the steam generator great improvements are noticeable."



A MODEL OF THE NEWCOMEN ENGINE.

This engine has particular interest not only because it was a practical pumping engine, but also because it was while repairing an engine of this type that Watt was led to the experiments that resulted in his epoch-making discovery.

THE COMING OF JAMES WATT

The Newcomen engine had low working efficiency as compared with the modern engine; nevertheless, some of these engines are still used in a few collieries where waste coal is available, the pressure enabling the steam to be generated in boilers unsafe for other purposes. The great importance of the Newcomen engine, however, is historical; for it was while engaged in repairing a model of one of these engines that James Watt was led to invent his plan of condensing the steam, not in the working cylinder itself, but in a separate vessel,—the principle upon which such vast improvements in the steam engine were to depend.

It is impossible to overestimate the importance of the work which Watt accomplished in developing the steam engine. Fully to appreciate it, we must understand that up to this time the steam engine had a very limited sphere of usefulness. The Newcomen engine represented the most developed form, as we have seen; and this, like the others that it had so largely superseded, was employed solely for the pumping of water. In the main, its use was confined to mines, which were often rendered unworkable because of flooding. We have already seen that a considerable number of engines were in use, yet their power in the aggregate added but a trifle to man's working efficiency, and the work that they did accomplish was done is a most uneconomical manner. Indeed the amount of fuel required was so great as to prohibit their use in many mines, which would have been valuable could a cheaper means have been found of freeing them from water. Watt's inventions, as we shall see, accomplished this end, as well as various others that were not anticipated.

It was through consideration of the wasteful manner of action of the steam engine that Watt was led to give attention to the subject. The great inventor was a young man at the University of Glasgow. He had previously served an apprenticeship of one year with a maker of philosophical instruments in London, but ill health had prevented him from finishing his apprenticeship, and he had therefore been prohibited from practising his would-be profession in Glasgow. Finally, however, he had been permitted to work under the auspices of the University; and in due course, as a part of his official duties, he was engaged in repairing a model of the Newcomen engine. This incident is usually mentioned as having determined the line of Watt's future activity.

It should be recalled, however, that Watt had become a personal friend of the celebrated Professor Black, the discoverer of latent heat, and the foremost authority in the world, in this period, on the study of pneumatics. Just what share Black had in developing Watt's idea, or in directing his studies toward the expansive properties of steam, it would perhaps be difficult to say. It is known, however, that the subject was often under discussion; and the interest evinced in it by Black is shown by the fact that he subsequently wrote a history of Watt's inventions.

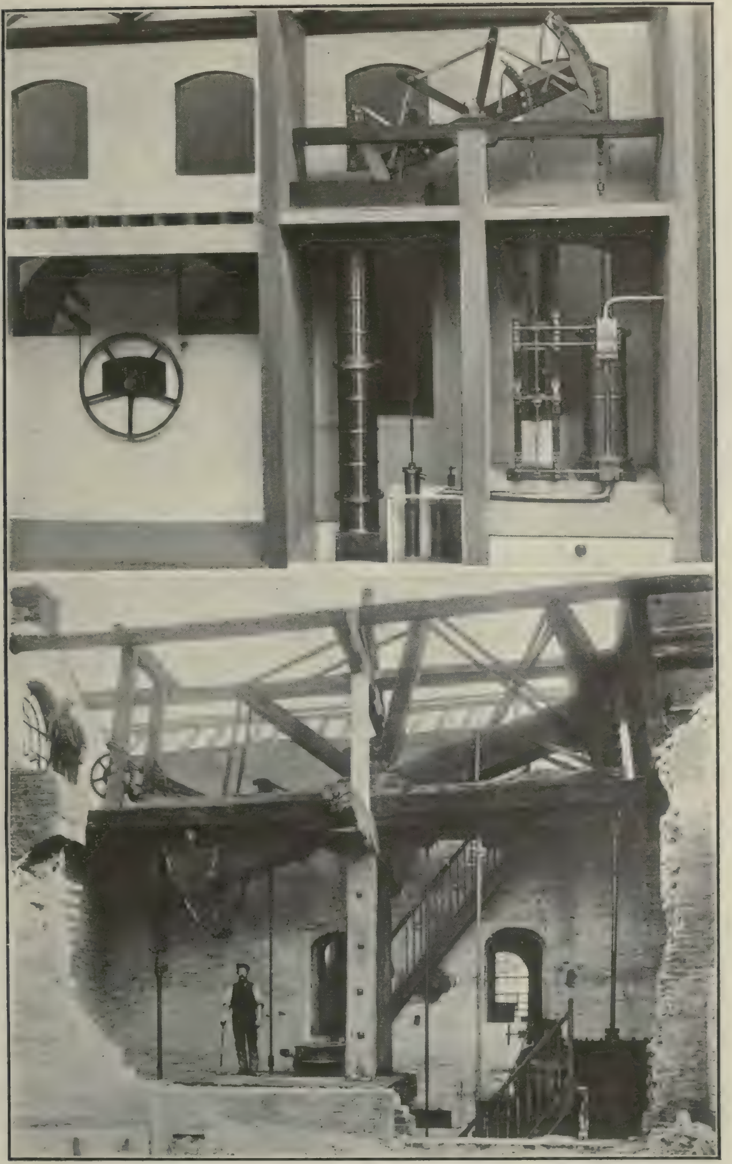
It is never possible, perhaps, for even the inventor himself to re-live the history of the growth of an idea in his own mind. Much less is it possible for him to say precisely what share of his progress has been due to chance suggestions of others. But it is interesting, at least, to recall this association of Watt with the greatest experimenter of his age in a closely allied field. Questions of suggestion aside, it illustrates the technical quality of Watt's mind, making it obvious that he was no mere ingenious mechanic, who stumbled upon his invention. He was, in point of fact, a carefully trained scientific experimenter, fully equipped with all the special knowledge of his time in its application to the particular branch of pneumatics to which he gave attention.

The first and most obvious defect in the Newcomen engine was, as Watt discovered, that the alternating cooling and heating of the cylinder resulted in an unavoidable waste of energy. The apparatus worked, it will be recalled, by the introduction of steam into a vertical cylinder beneath the piston, the cylinder being open above the piston to admit the air. The piston rod connected with a beam suspended in the middle, which operated the pump, and which was weighted at one end in order to facilitate the raising of the piston. The steam, introduced under low pressure, scarcely more than counteracted the pressure of the air, the raising of the piston being largely accomplished by the weight in question.

Of course the introduction of the steam heated the cylinder. In order to condense the steam and produce a vacuum, water was injected, the cylinder being thereby cooled. A vacuum being thus produced beneath the cylinder, the pressure of the air from above thrust the cylinder down, this being the actual working agent. It was for this reason that the Newcomen engine was called, with much propriety, a pneumatic engine. The action of the engine was very slow, and it was necessary to employ a very large piston in order to gain a considerable power.

The first idea that occurred to Watt in connection with the probable improvement of this mechanism did not look to the alteration of any of the general features of the structure, as regards size or arrangement of cylinder, piston, or beam, or the essential principle upon which the engine worked. His entire attention was fixed on the discovery of a method by which the loss of heat through periodical cooling of the cylinder could be avoided. We are told that he contemplated the subject long, and experimented much, before he reached a satisfactory solution. Naturally enough his attention was first directed toward the cylinder itself. He queried whether the cylinder might not be made of wood, which, through its poor conduction of heat, might better equalize the temperature. Experiments in this direction, however, produced no satisfactory result.

Then at last an inspiration came to him. Why not connect the cylinder with another receptacle, in which the condensation of the steam could be effected? The idea was a brilliant one, but neither its originator nor any other man of the period could possibly have realized its vast and all-comprehending importance. For in that idea was contained the germ of all the future of steam as a motive power. Indeed, it scarcely suffices



WATT'S EARLIEST TYPE OF PUMPING ENGINE.

The lower figure shows the ruins of Watt's famous engine "Old Bess." The upper figure shows a reconstructed model of the "Old Bess" engine. It will be noted that the walking beam is precisely of the Newcomen type. In fact, the entire engine is obviously only a modification of the Newcomen engine. It had, however, certain highly important improvements, as described in the text.

to speak of it as the germ merely; the thing itself was there, requiring only the elaboration of details to bring it to perfection.

Watt immediately set to work to put his brilliant conception of the separate condenser to the test of experiment. He connected the cylinder of a Newcomen engine with a receptacle into which the steam could be discharged after doing its work on the piston. The receptacle was kept constantly cooled by a jet of water, this water and the water of condensation, together with any air or uncondensed steam that might remain in the receptacle, being constantly removed with the aid of an air pump. The apparatus at once demonstrated its practical efficiency,—and the modern steam engine had come into existence.

It was in the year 1765, when Watt was twenty-nine years old, that he made his first revolutionary experiment, but his first patents were not taken out until 1769, by which time his engine had attained a relatively high degree of perfection. In furthering his idea of keeping the cylinder at an even temperature, he had provided a covering for it, which might consist of wood or other poorly conducting material, or a so-called jacket of steam—that is to say, a portion of steam admitted into the closed chamber surrounding the cylinder. Moreover, the cylinder had been closed at the top, and a portion of steam admitted above the piston, to take the place of the atmosphere in producing the down stroke. This steam above the piston, it should be explained, did not connect with the condensing receptacle, so the engine was still single-acting; that is to say it performed work only during one stroke of the piston. A description of the mechanism at this stage of its development may best be given in the words of the inventor himself, as contained in his specifications in the application for patent on his improvements in 1769.

"My method of lessening the consumption of steam, and consequently fuel, in fire-engines, consists of the following principles:

"First, That vessel in which the powers of steam are to be employed to work the engine, which is called the cylinder in common fire-engines, and which I call the steam vessel, must, during the whole time the engine is at work, be kept as hot as the steam that enters it; first by enclosing it in a case of wood, or any other materials that transmit heat slowly; secondly, by surrounding it with steam or other heated bodies; and, thirdly, by suffering neither water nor any other substance colder than the steam to enter or touch it during that time.

"Secondly, In engines that are to be worked wholly or partially by condensation of steam, the steam is to be condensed in vessels distinct from the steam vessels or cylinders, although occasionally communicating with them; these vessels I call condensers; and, whilst the engines are working, these condensers ought at least to be kept as cold as the air in the neighborhood of the engines, by application of water or other cold bodies.

"Thirdly, Whatever air or other elastic vapor is not condensed by the cold of the condenser, and may impede the working of the engine, is to be drawn out of the steam vessels or condensers by means of pumps, wrought by the engines themselves, or otherwise.

"Fourthly, I intend in many cases to employ the expansive force of steam to press on the pistons, or whatever may be used instead of them, in the same manner in which the pressure of the atmosphere is now employed in common fire-engines. In cases where cold water can not be had in plenty, the engines may be wrought by this force of steam only, by discharging the steam into the air after it has done its office.

"Sixthly, I intend in some cases to apply a degree of cold not capable of reducing the steam to water, but of contracting it considerably, so that the engines shall be worked by the alternate expansion and contraction of the steam.

"Lastly, Instead of using water to render the pistons and other parts of the engine air- and steam-tight, I employ oils, wax, resinous bodies, fat of animals, quicksilver and other metals in their fluid state."

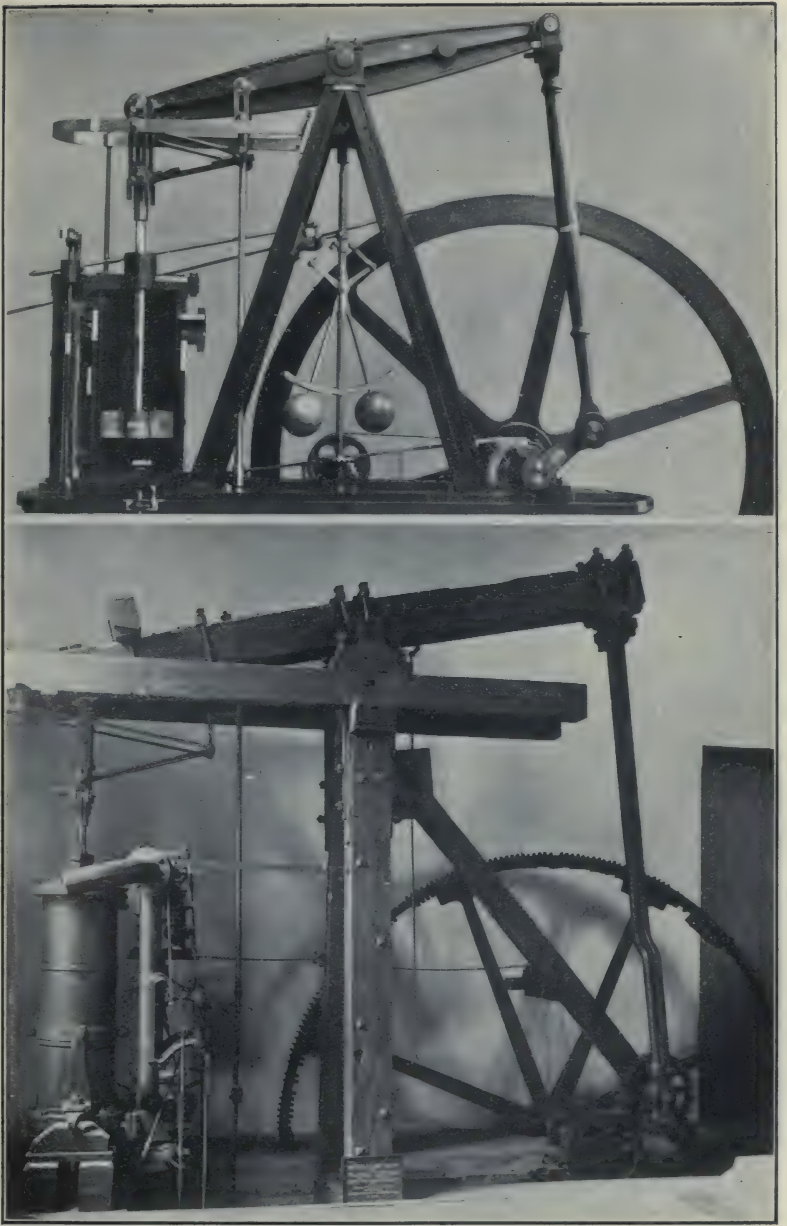
ROTARY MOTION

It must be understood that Watt's engine was at first used exclusively as an apparatus for pumping. For some time there was no practical attempt to apply the mechanism to any other purpose. That it might be so applied, however, was soon manifest, in consideration of the relative speed with which the piston now acted. It was not until 1781, however, that Watt's second patent was taken out, in which devices are described calculated to convert the reciprocating motion of the piston into motion of rotation, in order that the engine might drive ordinary machinery.

It seems to be conceded that Watt was himself the originator of the idea of making the application through the medium of a crank and fly-wheel such as are now universally employed. But the year before Watt took out his second patent, another inventor named James Picard had patented this device of crank and connecting rod, having, it is alleged, obtained the idea from a workman in Watt's employ. Whatever be the truth as to this point, Picard's patent made it necessary for Watt to find some alternative device, and after experimenting, he hit upon the so-called sun and planet gearing, and henceforth this was used on his rotary engines until the time for the expiration of Picard's patent, after which the simpler and more satisfactory crank and fly-wheel were adopted.

In the meantime, Watt had associated himself with a business partner named Boulton, under the firm name of Boulton and Watt. In 1776 a special act of legislation extending the term of Watt's original patent for a period of twenty-five years had been secured. All infringements were vigorously prosecuted, and the inventor, it is gratifying to reflect, shared fully in the monetary proceeds that accrued from his invention.

Notwithstanding the early recognition of the possibility of securing rotary motion with Watt's perfected Newcomen engine, it was long before the full possibilities of the application of this principle were realized, even by the most practical of machinists. Watt himself apparently appreciated the possibilities



WATT'S ROTATIVE ENGINE.

The lower figure shows the earliest type of mechanism through which Watt applied his engine to other uses than that of pumping. The so-called sun-and-planet gearing, through which rotary motion was attained, is seen at the lower right-hand corner of the figure. The upper figure shows a later and much improved type of the Watt engine, in which the sun-and-planet gearing has been supplanted by a simple crank.

no more fully than the others, as the use of his famous engines "Beelzebub" and "Old Bess" in the establishment of Boulton and Watt amply testifies. It appears that Boulton had been an extensive manufacturer of ornamental metal articles. To drive his machinery at Soho he employed two large water wheels, twenty-four feet in diameter and six feet wide. These sufficed for his purpose under ordinary conditions, but in dry weather from six to ten horses were required to aid in driving the machinery. When Watt's perfected engine was available, however, this was utilized to pump water from the tail race back to the head race, that it might be used over and over. "Old Bess" had a cylinder thirty-three inches in diameter with seven-foot stroke, operating a pump twenty-four inches in diameter; it therefore had remarkable efficiency as a pumping apparatus. But of course it utilized, at best, only a portion of the working energy contained in the steam; and the water wheels in turn could utilize not more than fifty per cent. of the store of energy which the pump transferred to the water in raising it. Therefore, such use of the steam engine involved a most wasteful expenditure of energy.

It was long, however, before the practical machinists could be made to believe that the securing of direct rotary power from the piston could be satisfactorily accomplished. It was only after the introduction of higher speed and heavier fly-wheels, together with improved governors, that the speed of rotation was so equalized as to meet satisfactorily the requirements of the practical engineer, and ultimately to displace the wasteful method of securing rotary motion indirectly through the aid of pump and water wheel. It may be added, that the centrifugal governor, with which modern engines are provided to regulate their speed, was the invention of Watt himself.

FINAL IMPROVEMENTS AND MISSED OPPORTUNITIES

In the year 1782 Watt took out patents which contained specifications for the two additional improvements that constituted his final contribution to the production of the steam engine. The first of these provided for the connection of the cylinder chamber on each side of the piston with the condenser, so that the engine became double acting. The second introduced the very important principle,—from the standpoint of economy in the use of steam—of shutting off the supply of steam from the cylinder while the piston has only partially traversed its thrust, and allowing the remainder of the thrust to be accomplished through the expansion of the steam. The application of the first of these principles obviously adds greatly to the efficiency of the engine, and in practise it was found that the application of the second principle produces a very great saving in steam, and thus adds materially to the economical working of the engine.

All of Watt's engines continued to make use of the walking beam attached to the piston for the transmission of power; and engineers were very slow indeed to recognize the fact that in many—in fact in most—cases this contrivance may advantageously be done away with. The recognition of this fact constitutes one of the three really important advances that have been made in the steam engine since the time of Watt. The other two advances consist of the utilization of steam under high pressure, and of the introduction of the principle of the compound engine.

Neither of these ideas was unknown to Watt, since the utilization of steam under high pressure was advocated by his contemporary, Trevithick, while the compound engine was invented by another contemporary named Hornblower. Perhaps the very fact that these rival inventors put forward the ideas in question may have influenced Watt to antagonize them; in particular since his firm came into legal conflict with each of the other inventors. At any rate, Watt continued to the end of his life to be an ardent advocate of low pressure for the steam engine, and his firm even attempted to have laws passed making it illegal—on the ground of danger to human life—to utilize high-pressure steam, such as employed by Trevithick.

Possibly the conservatism of increasing age may also have had its share in rendering Watt antagonistic to the new ideas; for he was similarly antagonistic to the idea of applying steam to the purposes of locomotion. Trevithick, among others, had, as we shall see in due course, made such application with astonishing success, producing a steam automobile which traversed the highway successfully. In his earlier years Watt had conceived the same idea, and had openly expressed his opinion that the steam engine might be used for this purpose. But late in life he was so antipathetic to the idea that he is said to have put a clause in the lease of his house, providing that no steam carriage should under any pretext be allowed to approach it.

These incidents have importance as showing—as we shall see illustrated again and again in other fields—the disastrous influence in retarding progress that may be exercised by even the greatest of scientific discoverers, when authority well earned in earlier years is exercised in an unfortunate direction later in life. But such incidents as these are inconsequential in determining the position among the world's workers of the man who was almost solely responsible for the transformation of the steam engine from an expensive and relatively ineffective pumping apparatus, to the great central power that has ever since moved the major part of the world's machinery.

THE SUPREME IMPORTANCE OF WATT

It is speaking well within bounds to say that no other invention within historical times has had so important an influence upon the production of property—which, as we have seen, is the gauge of the world's work—as this invention of the steam engine. We have followed the history of that invention in some detail, because of its supreme importance. To the reader who was not previously familiar with that history, it may seem surprising that after a lapse of a little over a century one name and one alone should be popularly remembered in connection with the invention; whereas in point of fact various workers had a share in the achievement, and the man whose name is remembered was among the last to enter the field. We have seen that the steam engine existed as a practical working machine several decades before Watt made his first invention; and that what Watt really accomplished was merely the perfecting of an apparatus which already had attained a considerable measure of efficiency.

There would seem, then, to be a certain lack of justice in ascribing supreme importance to Watt in connection with the steam engine. Yet this measure of injustice we shall find, as we examine the history of various inventions, to be meted always by posterity in determining the status of the men whom it is pleased to honor. One practical rule, and one only, has always determined to whom the chief share of glory shall be ascribed in connection with any useful invention.

The question is never asked as to who was the originator of the idea, or who made the first tentative efforts towards its utilization,—or, if asked by the historical searcher, it is ignored by the generality of mankind.

So far as the public verdict, which in the last resort determines fame, is concerned, the one question is, Who perfected the apparatus so that it came to have general practical utility? It may be, and indeed it usually is the case, that the man who first accomplished the final elaboration of the idea, made but a comparatively slight advance upon his predecessors; the early workers produced a machine that was *almost* a success; only some little flaw remained in their plans. Then came the perfecter, who hit upon a device that would correct this last defect,—and at last the mechanism, which hitherto had been only a curiosity, became a practical working machine.

In the case of the steam engine, it might be said that even a smaller feat than this remained to be accomplished when Watt came upon the scene; since the Newcomen engine was actually a practical working apparatus. But the all-essential thing to remember is that this Newcomen engine was used for a single purpose. It supplied power for pumping water, and for nothing else. Neither did it have possibilities much beyond this, until the all-essential modification was suggested by Watt, of exhausting its steam into exterior space.

This modification is in one sense a mere detail, yet it illustrates once more the force of Michelangelo's famous declaration that trifles make perfect; for when once it was tested, the whole practical character of the steam engine was changed. From a wasteful consumer of fuel, capable of running a pump at great expense, it became at once a relatively economical user of energy, capable of performing almost any manner of work.

Needless to say, its possibilities in this direction were not immediately realized, in theory or in practise; yet the conquest that it made of almost the entire field of labor resulted in the most rapid transformation of industrial conditions that the world has ever experienced. After all, then, there is but little injustice in that public verdict which remembers James Watt as the inventor, rather than as the mere perfecter, of the steam engine.

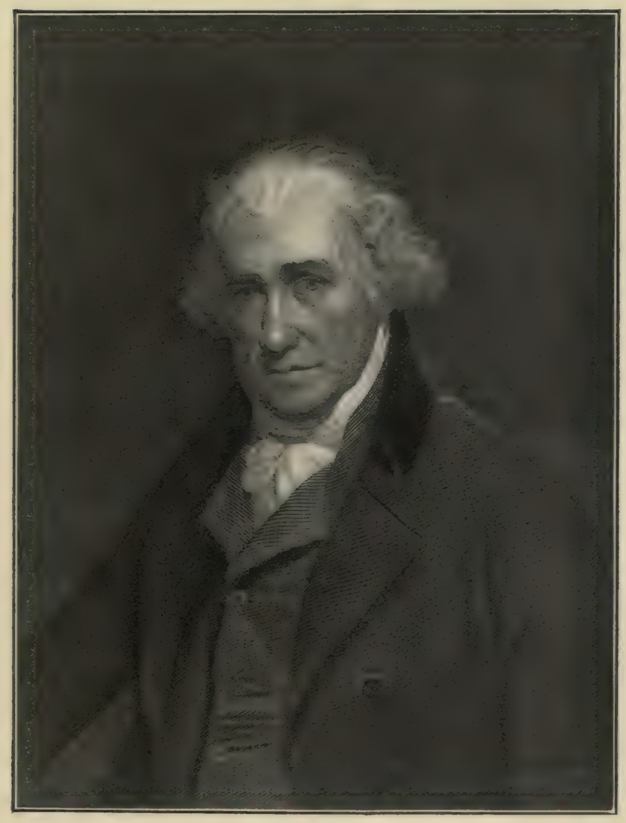
THE PERSONALITY OF JAMES WATT

The man who occupies this all-important position in the industrial world demands a few more words as to his personality. His work we have sufficiently considered, but before we pass on to the work of his successors, it will be worth our while to learn something more of the estimate placed upon the man himself. Let us quote, then, from some records written by men who were of the same generation.

"Independently of his great attainments in mechanics, Mr. Watt was an extraordinary and in many respects a wonderful man. Perhaps no individual in his age possessed so much, or remembered what he had read so accurately and well. He had infinite quickness of apprehension, a prodigious memory, and a certain rectifying and methodizing power of understanding which extracted something precious out of all that was presented to it. His stores of miscellaneous knowledge were immense, and yet less astonishing than the command he had at all times over them. It seemed as if every subject that was casually started in conversation had been that which he had been last occupied in studying and exhausting; such was the copiousness, the precision, and the admirable clearness of the information which he poured out upon it without effort or hesitation. Nor was this promptitude and compass of knowledge confined, in any degree, to the studies connected with his ordinary pursuits.

"That he should have been minutely and extensively skilled in chemistry, and the arts, and in most of the branches of physical science, might, perhaps, have been conjectured; but it could not have been inferred from his usual occupations, and probably is not generally known, that he was curiously learned in many branches of antiquity, metaphysics, medicine, and etymology, and perfectly at home in all the details of architecture, music, and law. He was well acquainted, too, with most of the modern languages, and familiar with their most recent literature. Nor was it at all extraordinary to hear the great mechanician and engineer detailing and expounding, for hours together, the metaphysical theories of the German logicians, or criticizing the measures or the matter of the German poetry.

"It is needless to say, that with those vast resources, his conversation was at all times rich and instructive in no ordinary degree. But it was, if possible, still more pleasing than wise, and had all the charms of familiarity, with all the substantial treasures of knowledge. No man could be more social in his spirit, less assuming or fastidious in his manners, or more kind and indulgent towards all who approached him. His talk, too, though overflowing with information, had no resemblance to lecturing, or solemn discoursing; but, on the contrary, was full of colloquial spirit and pleasantry. He had a certain quiet and grave humor, which ran through most of his conversation, and a vein of temperate jocularity, which gave infinite zest and effect to the condensed and inexhaustible information which formed its main staple and characteristic. There was a little air of affected testiness, and a tone of pretended rebuke and contradiction, which he used towards his younger



JAMES WATT.

friends, that was always felt by them as an endearing mark of his kindness and familiarity, and prized accordingly, far beyond all the solemn compliments that proceeded from the lips of authority. His voice was deep and powerful; though he commonly spoke in a low and somewhat monotonous tone, which harmonized admirably with the weight and brevity of his observations, and set off to the greatest advantage the pleasant anecdotes which he delivered with the same grave tone, and the same calm smile playing soberly on his lips.

"There was nothing of effort, indeed, or of impatience, any more than of pride or levity, in his demeanor; and there was a finer expression of reposing strength, and mild self-possession in his manner, than we ever recollect to have met with in any other person. He had in his character the utmost abhorrence for all sorts of forwardness, parade, and pretension; and indeed never failed to put all such impostors out of countenance, by the manly plainness and honest intrepidity of his language and deportment.

"He was twice married, but has left no issue but one son, associated with him in his business and studies, and two grandchildren by a daughter who predeceased him. He was fellow of the Royal Societies both of London and Edinburgh, and one of the few Englishmen who were elected members of the National Institute of France. All men of learning and of science were his cordial friends; and such was the influence of his mild character, and perfect fairness and liberality, even upon the pretender to these accomplishments, that he lived to disarm even envy itself, and died, we verily believe, without a single enemy."

VI

THE MASTER WORKER

WE have already pointed out at some length that, in the hands of Watt, the steam engine came at once to be a relatively perfect apparatus, and that only three really important modifications have been applied to it since the day of its great perfecter. These modifications, as already named, are the doing away with the walking beam, the utilization of high pressure steam, and the development of the compound engine. Each of these developments requires a few words of explanation.

The retention of the heavy walking beam for so long a time after the steam engine of Watt had been applied to the various purposes of machinery, illustrates the power of a pre-conceived idea. With the Newcomen engine this beam was an essential, since it was necessary to have a weight to assist in raising the piston. But with the introduction of steam rather than air as the actual power to push the piston, and in particular with the elaboration of the double-chamber cylinder, with steam acting equally on either side of the piston, the necessity for retaining this cumbersome contrivance no longer existed. Yet we find all the engines made by Watt himself, and nearly all those of his contemporaries, continuing to utilize this means of transmitting the power of the piston. Even the road locomotive, as illustrated by that first wonderful one of Trevithick's and such colliery locomotives as "Puffing Billy" and "Locomotion," utilized the same plan. It was not until almost a generation later that it became clear to the mechanics that in many cases, indeed in most cases, this awkward means of transmitting power was really a needlessly wasteful one, and that with the aid of fly-wheel and crank-shaft the thrust of the piston might be directly applied to the wheel it was destined to turn, quite as well as through the intermediary channel of the additional lever.

The utility of the beam has, indeed, still commended it for certain purposes, notably for the propulsion of side-wheel steamers, such as the familiar American ferryboat. But aside from such exceptional uses, the beam has practically passed out of existence.

There was no new principle involved in effecting this change. It was merely another illustration of the familiar fact that it is difficult to do things simply. As a rule, inventors fumble for a long time with roundabout and complex ways of doing things, before a direct and simple method occurs to them. In other words, the highest development often passes from the complex to the simple, illustrating, as it were, an oscillation in the great law of evolution. So in this case, even so great an inventor as Watt failed to see the utility of doing away with the cumbersome structure which his own invention had made no longer a necessity, but rather a hindrance to the application of the steam engine. However, a new generation, no longer under the thraldom of the ideas of the great inventor, was enabled to make the change, gradually, but in the end effectively.

HIGH-PRESSURE STEAM

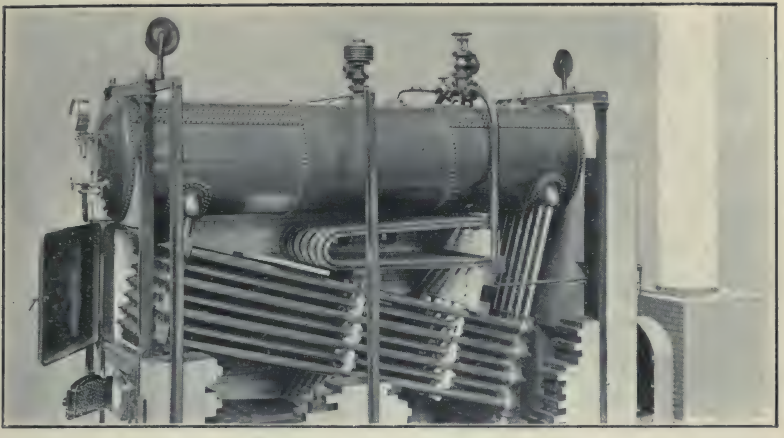
As regards the use of steam under high pressure, somewhat the same remarks apply, so far as concerns the conservatism of mankind, and the influence which a great mind exerts upon its generation. Just why Watt should have conceived an antagonism to the idea of high-pressure steam is not altogether clear. It has been suggested, indeed, that this might have been due to the fact that a predecessor of Watt had invented a high-pressure engine which did not use the principle of condensation, but exhausted the steam into open space. As early as 1725, indeed, Leupold in his *Theatrum Machinarum*, had described such a non-condensing engine, which, had it been made practically useful, would have required a high pressure of steam. Partly through the influence of this work, perhaps, there came to be an association between the words high pressure and non-condensing, so that these terms are considered to be virtually synonymous; and since Watt's great contribution consisted of an application of the idea of condensation, he was perhaps rendered antagonistic to the idea of high pressure, through this psychological suggestion. In any event, the antagonism unquestionably existed in his mind; though it has often enough been pointed out that this seems the more curious since high-pressure steam would so much better have facilitated the application of that other famous idea of Watt, the use of the expansive property of steam.

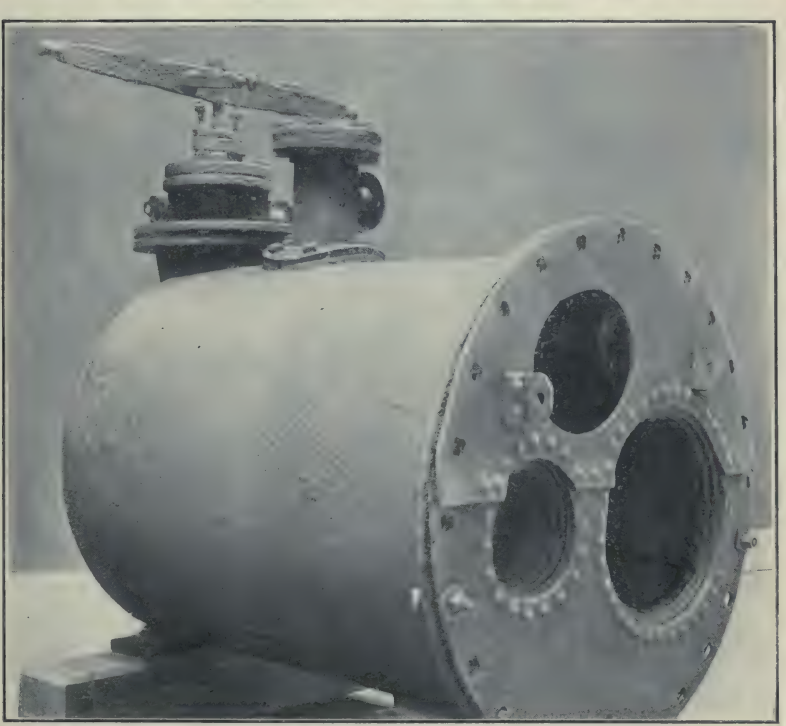
Curiously enough, however, the influence of Watt led to experiments in high-pressure steam through an indirect channel. The contemporary inventor, Trevithick, in connection with his partner, Bull, had made direct-acting pumping engines with an inverted cylinder, fixed in line with the pump rod, and actually dispensing with the beam. But as these engines used a jet of cold water in the exhaust pipe to condense the steam, Boulton and Watt brought suit successfully for infringement of their patent, and thus prevented Trevithick from experimenting further in that direction. He was obliged, therefore, to turn his attention to a different method, and probably, in part at least, in this way was led to introduce the non-condensing, relatively high-pressure engine. This was used about the year 1800. At the same time somewhat similar experiments were made by Oliver Evans in America.

Both Trevithick and Evans applied their engines to the propulsion of road vehicles; and Trevithick is credited with being the first man who ran a steam locomotive on a track,—a feat which he accomplished as early as the year 1804. We are not here concerned with the details of this accomplishment, which will demand our attention in a later chapter, when we come to discuss the entire subject of locomotive transportation. But it is interesting to recall that the possibilities of the steam engine were thus early realized, even though another generation elapsed before they were finally demonstrated to the satisfaction of the public. It is particularly interesting to note that in his first locomotive engine, Trevithick allowed the steam exhaust to escape into the funnel of the engine to increase the draught,—an expedient which was so largely responsible for Stephenson's success with his locomotive twenty years later, and which retains its utility in the case of the most highly developed modern locomotive.

Trevithick was, however, entirely subordinated by the great influence of Watt, and the use of high pressure was in consequence discountenanced by the leading mechanical engineers of England for some decades. Meantime, in America, the initiative of Evans led to a much earlier general use of high-pressure steam. In due course, however, the advantages of steam under high pressure became evident to engineers everywhere, and its conquest was finally complete.

The essential feature of super-heated steam is that it contains, as the name implies, an excess of heat beyond the quantity necessary to produce mere vaporization, and that the amount of water represented in this vapor is not the maximum possible under given conditions. In other words, the vapor is not saturated. It has been already explained that the amount of vapor that can be taken up in a given space under a given pressure varies with the temperature of the space. Under normal conditions, when a closed space exists above a liquid, evaporation occurs from the surface of the liquid until the space is saturated, and no further evaporation can occur so long as the temperature and pressure are unchanged. If now the same space is heated to a higher degree, more vapor will be taken up until again the point of saturation is attained. But, obviously, if the space were disconnected with the liquid, and





OLD IDEAS AND NEW APPLIED TO BOILER CONSTRUCTION.

The lower figure shows Robert Trevethick's famous boiler, used in operating his locomotive about the year 1804. The original is preserved in the South Kensington Museum, London. The upper figure shows a modern tubular boiler, by way of contrast.

then heated, it would acquire a capacity to take up more vapor, and so long as this capacity was latent, the vapor present would exist in a super-heated condition.

It will be understood from what has been said before, that with all accessions of heat, the expansive power of the vapor is increased,—its molecules becoming increasingly active; hence one of the very obvious advantages of super-heated steam for the purpose of pushing a piston. There are other advantages, however, which are not at first sight so apparent, having to do with the properties of condensation. To understand these, we must pay heed for a few moments to the changes that take place in steam itself in the course of its passage through the cylinder, where it performs its work upon the piston.

Many of these changes were not fully understood by the earlier experimenters, including Watt. Indeed the theory of the steam engine, or rather the general theory of the heat engine, was not worked out until the year 1824, when the Frenchman Carnot took the subject in hand, and performed a series of classical experiments, which led to a nearly complete theoretical exposition of the subject. It remained, however, for the students of thermo-dynamics, about the middle of the nineteenth century, with Clausius and Rankine at their head, to perfect the theory of the steam engine, and the general subject of the mutual relations of heat and mechanical work.

We are not here concerned with any elaboration of details, but merely with a few of the essential principles which enter practically into the operation of the steam engine. It appears, then, that when steam enters the cylinder and begins to thrust back the piston of the steam engine, a portion of the steam is immediately condensed on the walls of the cylinder, owing to the fact that previous condensation of steam has cooled these walls to a certain extent. We have already pointed out that Watt endeavored in his earlier experiments to overcome this difficulty, by equalizing the temperature of the cylinder walls to the greatest practicable extent.

Notwithstanding his efforts, however, and those of numberless later experimenters, it still remains true that under ordinary conditions, particularly if steam enters the cylinder at the saturation point, a very considerable condensation occurs. Indeed this may amount to from thirty to fifty per cent. of the entire bulk of water contained in the quantity of steam that enters the cylinder. This condensation obviously militates against the expansive or working power of the steam. But now as the steam expands, pushing forward the cylinder, it becomes correspondingly rarefied, and immediately a portion of the condensed steam becomes again vaporized, and in so doing it takes up a certain amount of heat and renders it latent. This disadvantageous cycle of molecular transformations is very much modified in the case of super-heated steam, for the obvious reason that such steam may be very much below the saturation point, and hence requires a very much greater lowering of temperature in order to produce condensation of any portion of its mass. Without elaborating details, it suffices to note that in all highly efficient modern engines, steam is employed at a relatively high pressure, and that sometimes this pressure becomes enormous.

COMPOUND ENGINES

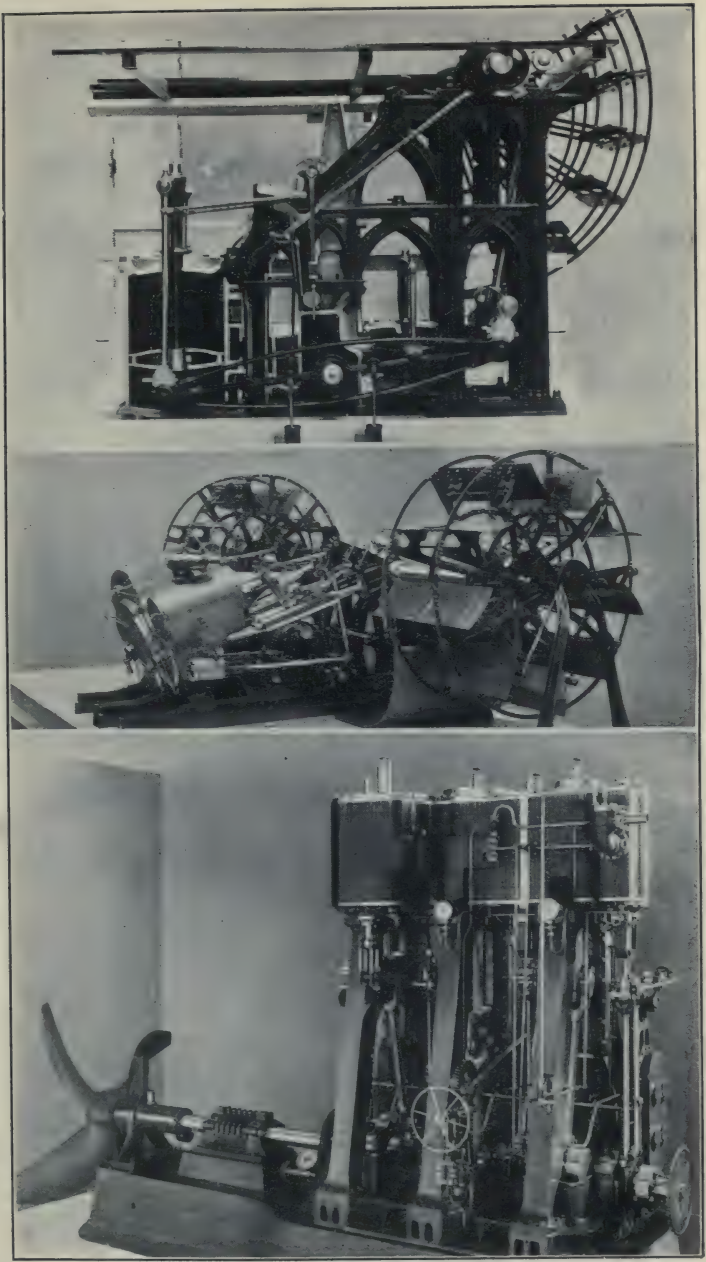
As to the compound engine, that also, as has been pointed out, was invented by a contemporary of Watt, Jonathan Hornblower by name, whose patent bears date of 1781. In Hornblower's engine, steam was first admitted to a small cylinder, and then, after performing its work on the piston, was allowed to escape, not into a condensing receptacle, but into a larger cylinder where it performed further work upon another piston. This was obviously an instance of the use of steam expansively, and it has been pointed out that, in consequence, Hornblower was the first to make use of this idea in practise, although it is said that Watt's experiments had even at that time covered this field. The application of the idea to the movement of the second cylinder, however, appears to have been original with Hornblower. Certainly it owed nothing to Watt, who refused to accept the idea, and continued throughout his life to frown upon the compound engine.

Nevertheless, the device had great utility, as subsequent experiments were very fully to demonstrate. The compound engine was revived by Woolf in 1804, and his name rather than Hornblower's is commonly associated with it. The latter experimenter demonstrated that the compound engine has two important merits as against the simple engine. One of these is that the sum of the two forces exerted by the joint action results in a more even and continuous pressure throughout the cycle than could be accomplished by the action of a single cylinder.

To understand this it must be recalled that when using the expansive property of steam, the piston thrust could not possibly be uniform, since the greatest pressure exerted by the steam would be exerted at the moment before it was shut off from the boiler, and its pressure must then decrease progressively, as it exerts more and more work upon the piston and becomes more expanded, thus obviously retaining less elastic energy. The operation of the fly-wheel largely compensates this difference of pressure in practise, but it would be obviously advantageous could the pressure be equalized; and, as just stated, the compound engine tends to produce this result.

The second, and perhaps the more important merit of the compound engine is, that it is found in practise to keep the cylinders at a more uniform temperature. A moment's reflection makes it clear why this should be the case, since in a single-cylinder engine the exhaust connects with the cool condenser, whereas in the compound engine the exhaust from the first cylinder connects with the second cylinder at only slightly lower temperature.

In many modern engines a third cylinder and sometimes even a fourth is added, constituting what are called respectively triple-expansion and quadruple-expansion engines. The triple-expansion system is very generally employed, especially where it is peculiarly desirable to economize fuel, as, for example, in the case of ships.



COMPOUND ENGINES.

The lower figure illustrates the use of a modern compound engine, directly operating the propeller shaft of a steamship. The middle figure shows a similarly direct application of power to the axes of paddle wheels. The upper figure shows the application of power through a walking beam similar in principle to that of the original Newcomen and Watt engines.

ROTARY ENGINES

All these improvements, it will be observed, have to do with details that do not greatly modify the steam engine from the original type. The cylinder with its closely fitting piston, as introduced in the Newcomen engine, is retained and constitutes the essential mechanism through which the energy of steam is transferred into mechanical energy. But from a comparatively remote period the idea has prevailed that it might be possible to utilize a different principle; that, in short, if the steam instead of being made to press against a piston were allowed to rush against fan-like blades, adjusted to an axle, it might cause blades and axle to revolve, precisely as a windmill is made to revolve by the pressure of the wind, or the turbine wheel by the pressure of water.

In a word, it has been believed that a turbine engine might be constructed, which would utilize the energy of the steam as advantageously as it is utilized in the piston engine, and at the same time would communicate its power as a direct rotation, instead of as a straight thrust that must be translated into a rotary motion by means of a crank or other mechanism.

In point of fact, James Watt himself invented such an engine, and patented it in 1782, though there is no evidence that he ever constructed even a working model. His patent specifications show "a piston in the form of a closely-fitting radial arm, projecting from an axial shaft in a cylinder. An abutment, arranged as a flap is hinged near a recess in the side of the cylinder, and swings while remaining in contact with the piston. Steam is admitted to the chamber on one side of the flap, and so causes an unbalanced pressure upon the radial arm."

This arrangement has been re-invented several times. Essentially the same principle is utilized by Joshua Routledge, whose name is well known in connection with the engineer's slide-rule. A model of this engine is preserved in the South Kensington Museum, and the apparatus is described in the catalogue of the Museum as follows:

"The piston revolves on a shaft passing through the centre of the cylinder casing. The flap or valve hinged to the casing, with its free end resting upon the piston, acts like the bottom of an ordinary engine cylinder. The steam inlet port is on one side of the hinge, and the exhaust port on the other. The admission of steam is controlled by a side valve, actuated by an eccentric on the fly-wheel shaft, so that the engine could work expansively, and the steam pressure resisting the lifting of the flap would also be greatly reduced, so diminishing the knock at this point, which, however, would always be a serious cause of trouble. The exhaust steam passes down to a jet condenser, provided with a supply of water from a containing tank, from which the injection is admitted through a regulating valve. The air pump, which draws the air and water from the condenser and discharges them through a pipe passing out at the end of the tank, is a rotary machine constructed like the engine and driven by spur gearing from the fly-wheel shaft. Some efforts have been made to prevent leakage by forming grooves in the sides of the revolving piston and filling them with soft packing."

Sundry other rotary engines, some of them actual working models, are to be seen at the South Kensington Museum. There is, for example, one invented by the Rev. Patrick Bell, a gentleman otherwise known to fame as one of the earliest inventors of a practical reaping machine. In this apparatus, "A metal disc is secured to a horizontal axis carried in bearings, and the lower half of the disc is enclosed by a chamber of circular section having its axis a semi-circle. One end of this chamber is closed and provided with a pipe through which steam enters, the exhaust taking place through the open end. The disc is provided with three holes, each fitted with a circular plate turning on an axis radial to the disc, and these plates when set at right angles to the disc become pistons in the lower enclosing chamber. Toothed gearing is arranged to rotate these pistons into the plane of the disc on leaving the cylinder and back again immediately after entering, locking levers retaining them in position during the intervals. The steam pressure upon these pistons forces the disc round, but the engine is non-expansive, and although some provision for packing has been made, the leakage must have been considerable and the wear and tear excessive."

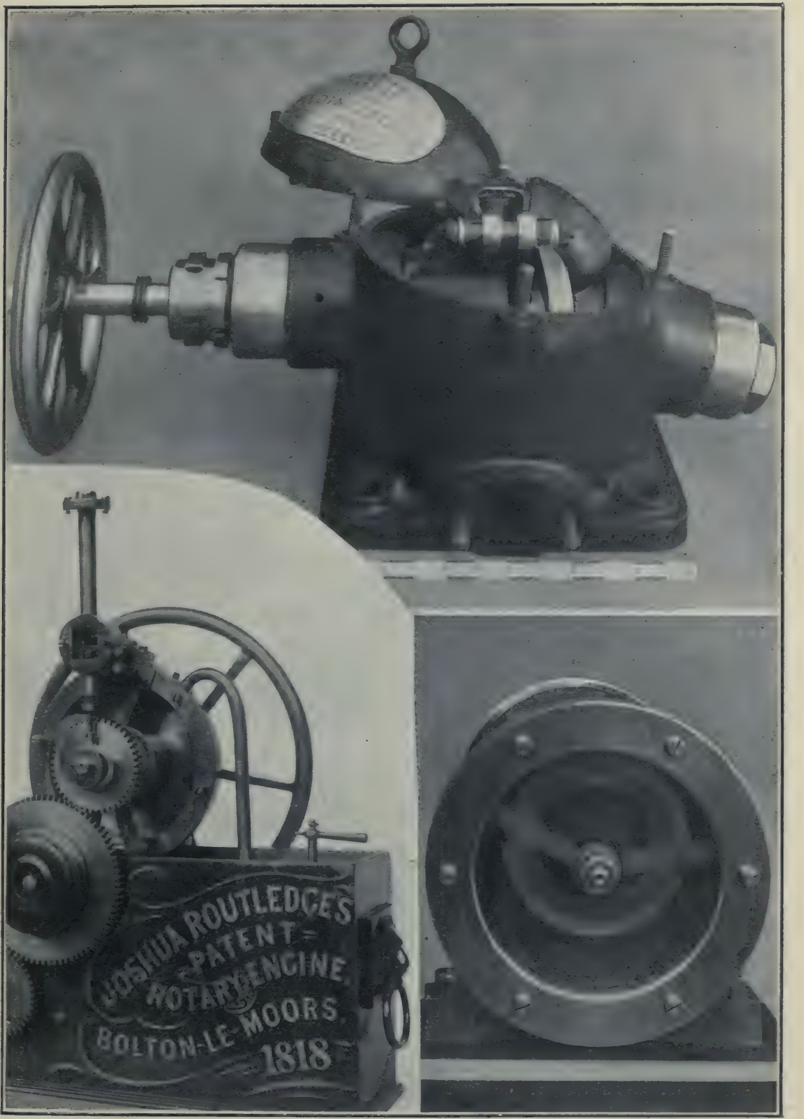
It is stated that almost the same arrangement was proposed by Lord Armstrong in 1838 as a water motor, and that a model subsequently constructed gave over five horse-power at thirty revolutions per minute, with an efficiency of ninety-five per cent.

Another working model of a rotary engine shown at the Museum is one loaned by Messrs. Fielding and Platt in 1888. "The action of this engine depends upon the oscillating motion which the cross of a universal joint has relative to the containing jaws when the system is rotated.

"Two shafts are set at an angle of 165 deg. to each other and connected by a Hooke's joint; one serves as a pivot, the power being taken from the other. Four curved pistons are arranged on the cross-piece, two pointing towards one shaft and two towards the other, and on each shaft or jaw are formed two curved steam cylinders in which the curved pistons work. The steam enters and leaves the base of each cylinder through ports in the shaft, which forms a cylindrical valve working in the bearing as a seating.

"On the revolution of the shafts the pistons reciprocate in their cylinders in much the same way as in an ordinary engine, and the valve arrangement is such that while each piston is receding from its cylinder the steam pressure is driving it, and during the in-stroke of each, its cylinder is in communication with the exhaust. There are thus four single-acting cylinders making each a double stroke for one revolution of the drlving-shaft. The engine has no dead centres, and has been at 1,000 revolutions per minute."

It is not necessary to describe other of the rotary engines that have been made along more or less similar lines by numerous inventors, models of which are for the most part, as in the case of those just described, to be seen more commonly in museums than in practical


JOSHUA ROUTLEDGE'S
PATENT
ROTARY ENGINE.
BOLTON-LE-MOORS.
1818

ROTARY ENGINES.

The three types of rotary engines here shown are similar in principle, and none of them is of great practical value, though the upper figure shows an engine that has met with a certain measure of commercial success.

workshops. Reference may be made, however, to a rotary engine which was invented by a Mr. Hoffman, of Buffalo, New York, about the beginning of the twentieth century, an example of which was put into actual operation in running the machinery of a shop in Buffalo, in 1905.

This engine consists of a solid elliptical shaft of steel, fastened to an axle at one side of its centre, which axis is also the shaft of the cylinder, which revolves about the central ellipse in such a way that at one part of the revolution the cylinder surface fits tightly against the ellipse, while the opposite side of the cylinder supplies a free chamber between the ellipse and the cylinder walls. Running the length of the cylinder are two curved pieces of steel, like longitudinal sections of a tube. These flanges are adjusted at opposite sides of the cylinder and so arranged that their sides at all times press against the ellipse, alternately retreating into the substance of the cylinder, and coming out into the free chamber. Steam is admitted to the free chamber through one end of the shaft of ellipse and cylinder and exhausted through the other end. The pressure of the steam against first one end and then the other of the flanges supplies the motive power. This pressure acts always in one direction, and the entire apparatus revolves, the cylinder, however, revolving more rapidly than the central ellipse.

For this engine the extravagant claim is made that there is no limit to its speed of revolution, within the limit of resistance of steel to centrifugal force. It has been estimated that a locomotive might be made to run two hundred or three hundred miles an hour without difficulty, with the Hoffman engine. Such estimates, however, are theoretical, and it remains to be seen what the engine can do in practise when applied to a variety of tasks, and what are its limitations. Certainly the apparatus is at once ingenious and simple in principle, and there is no obvious theoretical reason why it should not have an important future.

TURBINE ENGINES

Whatever the future may hold, however, it remains true that the first practical solution of the problem of securing direct rotary motion from the action of steam, on a really commercial scale, was solved with an apparatus very different from any of those just described, the inventor being an Englishman, Mr. C. A. Parsons, and the apparatus the steam turbine, the first model of which he constructed in 1884, and which began to attract general attention in the course of the ensuing decade. Public interest was fully aroused in 1897, when Mr. Parson's boat, the *Turbinia*, equipped with engines of this type, showed a trial speed of 32¾ knots per hour, a speed never hitherto attained by any other species of water craft. More recently, a torpedo boat, the *Viper*, equipped with engines developing about ten thousand horse-power, attained a speed of 35½ knots. The success of these small boats led to the equipment of large vessels with the turbine, and on April first, 1905, the first transatlantic liner propelled by this form of engine steamed into the harbor of Halifax, Nova Scotia.

This first ocean liner equipped with the turbine engine is called the *Victorian.* She is a ship five hundred and forty feet long and sixty feet wide, carrying fifteen hundred passengers. The *Victorian* had shown a speed of 19½ knots an hour on her trial trip, and it had been hoped that she would break the transatlantic record. On her first trip, however, she encountered adverse winds and seas, and did not attain great speed. Her performance was, however, considered entirely satisfactory and creditable.

In the ensuing half-decade several large ships were equipped with engines of the same type, the most famous of these being the Cunard liners, *Carmania*, *Lusitania*, and *Mauretania.* The two last-named ships are sister craft, and they are the largest boats of any kind hitherto constructed. The *Lusitania* was first launched and she entered immediately upon a record-breaking career, only to be surpassed within a few months by the *Mauretania*, which soon acquired all records for speed and endurance.

Fuller details as to the performance of these vessels will be found in another place. Here we are of course concerned with the Parsons turbine engine itself rather than with its applications.

This turbine engine constitutes the first really important departure from the old-type steam engine, thus realizing the dream of the seventeenth-century Italian, Branca, to which reference was made above. Mr. Parsons' elaboration of the idea developed a good deal of complexity as regards the number of parts involved, yet his engine is of the utmost simplicity in principle.

It consists of a large number of series of small blades, each series arranged about a drum which revolves. Between the rings of revolving blades are adjusted corresponding rings of fixed blades, which project from the casing to the cylinder, and by means of which the steam is regulated in direction, so that it strikes at the proper angle against the revolving blades of the turbine.

In practise, three series of cylindrical drums are used, each containing a large number of rings of blades of uniform size; but each successive drum having longer blades, to accommodate the greater volume of the expanding steam. The steam is fed against the first series of blades in gusts, which may be varied in frequency and length to meet the requirements of speed. After impinging on the first circle of blades, the steam passes to the next under slightly reduced pressure, and the pressure is thus successively stepped down from one set of blades to another until it is ultimately reduced from say two hundred pounds to the square inch, to one pound to the square inch before it passes to the condenser and ceases to act.

There is thus a fuller utilization of the kinetic energy of the gas, through carrying it from high to low pressure, than is possible with the old type of cylinder-and-piston engine. On the other hand, there is a constant loss due to the fact that the blades of the turbine can not fit with absolute tightness against the cylinder walls. The net result is that the compound turbine, as at present developed, appears to have about the same efficiency as the best engine of the old type.

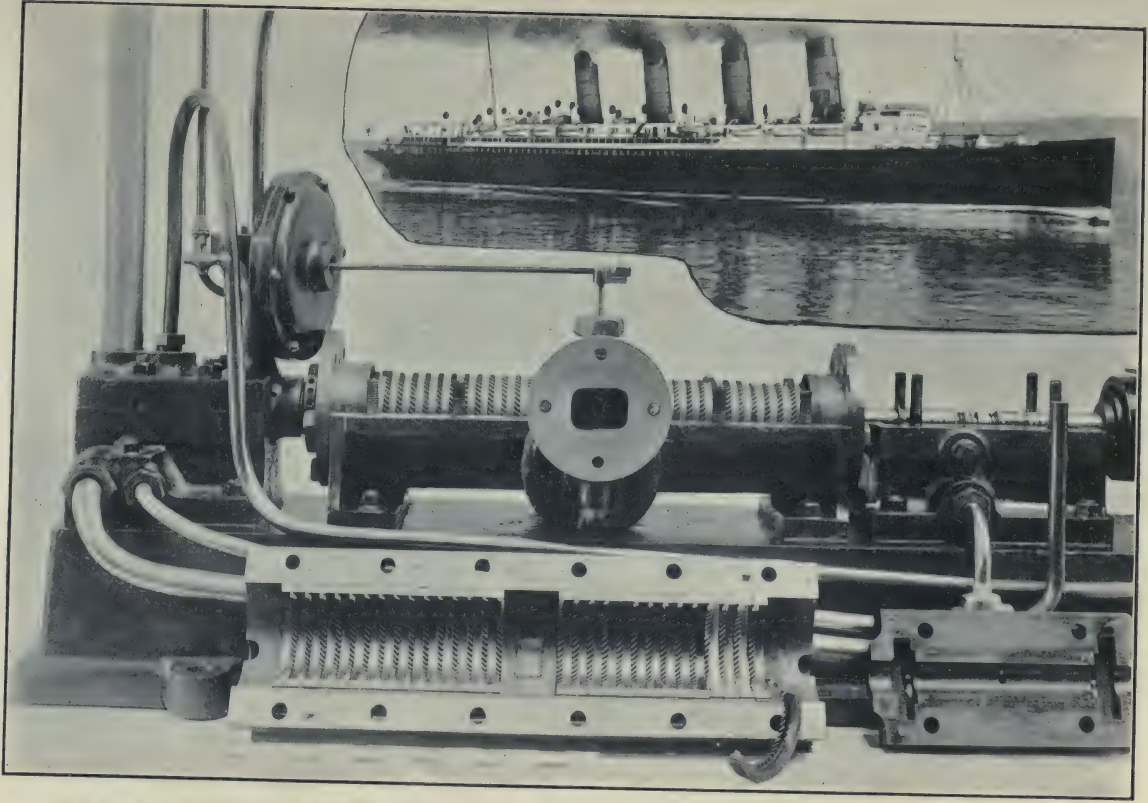
One capital advantage of the turbine is that it keeps the cylinder walls at a more uniform temperature than is possible even with a compound engine of the old type. Another advantage is that the power of the turbine is applied directly to cause rotation of the shaft, whereas no satisfactory means has ever been discovered hitherto of making the action of the steam engine rotary, except with the somewhat disadvantageous crank-shaft. This fact of adjustment of the turbine blades to the revolving shaft seems to make this form of engine particularly adapted to use in steamships. It is also highly adapted to revolving the shaft of a dynamo, and has been largely applied to this use. Needless to say, however, it may be applied to any other form of machinery. It would be difficult at the present stage of its development to predict the extent to which the turbine will ultimately supersede the old type of engine. Its progress has already been extraordinary, however, as an engineer pointed out in the London *Times* of August 14, 1907, in the following words:

"When the steam turbine was introduced by Mr. Parsons some 25 years ago, in the form of a little model, which is now in the South Kensington Museum, and the rotor of which may easily be held stationary by the hand against the full blast of the steam, who would have been rash enough to predict, except perhaps the far-seeing inventor himself, that a vessel 760 feet long, loaded to 37,000 tons displacement, drawing 32 ft. 9 in. of water, and providing accommodation for 2,500 people, could be propelled at a speed of 24.5 knots per hour, which it is hoped she may maintain over the 3,000 miles of the Atlantic voyage?

"From this small model, which will in time become as historic as the *Rocket* of Stephenson, and which is only some few inches in diameter, the turbine has been developed gradually in size. The cylindrical casings which take the place of the complicated machinery of the piston engine in the engine room of the *Lusitania* contain drums, which in the high-pressure turbines are 8 feet in diameter and in the low-pressure 11 ft. 8 in., and from which thousands of curved blades project, the longest of which are 22 inches, and against which the steam impinges in its course from the boiler to the condenser.

"Not only has the steam turbine justified the confidence of those who have labored so successfully in its development, but no other great invention has proceeded from the laboratory stage to such an important position in the engineering world in such a short space of time. This would not have happened if some inherent drawback, such as lack of economy in steam consumption, existed, and as the turbine has been proved to be, for land purposes, very economical, there seems to be no reason to doubt that marine turbines, working as they do at full load almost continually, will show likewise that the coal bill is not increased, but perhaps diminished by their use.

"The records of the vibrations of the hull which were taken during the trials by Schlick's instruments showed that the vertical vibration was 60 per minute on the run, which was due to the propellers, and which may be further modified. The horizontal vibration was almost unnoticeable, while the behavior of the



THE ORIGINAL PARSON'S TURBINE ENGINE AND THE RECORD-BREAKING SHIP FOR WHICH IT IS RESPONSIBLE.

This small turbine engine, with which Mr. Parson's early experiments were made in 1884, is preserved in the South Kensington Museum, London. At the time when it was made it seemed scarcely more than a toy, and engineers in general doubted that the principle it employed could ever be made commercially available. Yet within the lifetime of its inventor engines built on this model have come to be the most powerful of force transmuters. The "Mauretania," the largest, and thanks to her turbine engines the speediest, of ships, is here presented on the same page with the little original turbine model, as illustrating vividly the practical development

ship in the heavy seas she encountered in her long-distance runs was good, the roll from side to side having a period of 18 seconds. The great length of this ship and the gyrostatic action of the heavy rotating masses of the machinery ought to render her almost insensible to the heaviest Atlantic rollers; certainly as far as pitching is concerned."

A more general comment upon the turbine engine, with particular reference to its use in America, is made by Mr. Edward H. Sanborn in an article on *Motive Power Appliances*, in the Twelfth Census Report of the United States, Vol. X. part IV.

"Apart from its demonstrated economy," says Mr. Sanborn, "other important advantages are claimed for the steam turbine, some of which are worthy of brief mention.

"There is an obvious advantage in economy of space as compared with the reciprocating engine. The largest steam turbine constructed in the United States is one of 3,000 horse-power, which is installed in the power house of the Hartford Electric Light Company, Hartford, Conn. The total weight of this motor is 28,000 pounds, its length over all is 19 feet 8 inches, and its greatest diameter six feet. With the generator to which it is directly connected, it occupies a floor space of 33 feet 3 inches long by 8 feet 9 inches wide.

"Friction is reduced to a minimum in the steam turbine, owing to the absence of sliding parts and the small number of bearings. The absence of internal lubrication is also an important consideration, especially when it is desired to use condensers.

"As there are no reciprocating parts in a steam turbine, and as a perfect balance of its rotating parts is absolutely essential to its successful operation, vibration is reduced to such a small element that the simplest foundations will suffice, and it is safe to locate steam turbines on upper floors of a factory if this be desirable or necessary.

"The perfect balance of the moving parts and the extreme simplicity of construction tend to minimize the wear and increase the life of a turbine, and at the same time to reduce the chance of interruption in its operation through derangement of, or damage to, any of its essential parts.

"Although hardly beyond the stage of its first advent in the motive-power field, the steam turbine has met with much favor, and there is promise of its wide use for the purposes to which it is particularly adapted. At present, however, its uses are restricted to service that is continuous and regular, its particular adaptability being for the driving of electrical generators, pumps, ventilating fans, and similar work, especially where starting under load is not essential.

"Steam turbines are now being built in the United States in all sizes up to 3,000 horse-power. Their use abroad covers a longer period and has become more general. The largest turbines thus far attempted are those of the Metropolitan District Electric Traction Company, of London, embracing four units of 10,000 horse-power each. Several turbines of large size have been operated successfully in Germany."

It should be added that the compound turbine wheel of Parsons is not the only turbine wheel that has proved commercially valuable. There is a turbine consisting of a single ring of revolving blades, the invention of Dr. Gustav De Laval, which has proved itself capable of competing with the old type of engine. To make this form of single turbine operate satisfactorily, it is necessary to have steam under high pressure, and to generate a very high speed of revolution. In practice, the De Laval machines sometimes attain a speed of thirty thousand revolutions per minute. This is a much higher rate of speed than can advantageously be utilized directly in ordinary machinery, and consequently the shaft of this machine is geared to another shaft in such a way as to cause the second shaft to revolve much more slowly.

VII

GAS AND OIL ENGINES

JUST at the time when the type of piston-and-cylinder engine has thus been challenged, it has chanced that a new motive power has been applied to the old type of engine, through the medium of heated gas. The idea of such utilization of a gas other than water vapor is by no means new, but there have been practical difficulties in the way of the construction of a commercial engine to make use of the expansive power of ordinary gases.

The principle involved is based on the familiar fact that a gas expands on being heated and contracts when cool. Theoretically, then, all that is necessary is to heat a portion of air confined in a cylinder, to secure the advantage of its expansion, precisely as the expansion of steam is utilized, by thrusting forward a piston. Such an apparatus constitutes a so-called "caloric" or hot-air engine. As long ago as the year 1807 Sir G. Cayley in England produced a motor of this type, in which the heated air passed directly from the furnace to the cylinder, where it did work while expanding until its pressure was not greater than that of the atmosphere, when it was discharged. The chief mechanical difficulty encountered resulted from the necessity for the employment of very high temperatures; and for a long time the engine had no great commercial utility. The idea was revived, however, about three-quarters of a century later and an engine operated on Cayley's principle was commercially introduced in England by Mr. Buckett. This engine has a cold-air cylinder above the crank-shaft and a large hot-air cylinder below, while the furnace is on one side enclosed in an air-tight chamber. The fuel is supplied as required through a valve and distributing cone arranged above the furnace and provided with an air lock in which the fuel is stored. At about the time when this hot-air engine was introduced, however, gas and oil engines of another and more important type were developed, as we shall see in a moment.

Meantime, an interesting effort to utilize the expansive property of heated air was made by Dr. Stirling in 1826; his engine being one in which heat was distributed by means of a displacer which moved the mass of air to and fro between the hot and cold portions of the apparatus. He also compressed the air before heating it, thus making a distinct advance in the economy and compactness of the engine. From an engineering standpoint his design has further interest in that it was a practical attempt to construct an engine working on the principle of the theoretically perfect heat engine, in which the cycle of operations is closed, the same mass of air being used throughout. In the theoretically perfect heat engine, it may be added, the cycle of operations may be reversed, there being no loss of energy involved; but in practice, of course, an engine cannot be constructed to meet this ideal condition, as there is necessarily some loss through dissipation of heat. Dr. Stirling's practical engine had its uses, but could not compete with the steam engine in the general field of mechanical operations to which that apparatus is applied.

Another important practical experimenter in the construction of hot-air engines was John Ericsson, who in 1824 constructed an engine somewhat resembling the early one of Cayley, and in 1852 built caloric engines on such a scale as to be adapted to the propulsion of ships. Notwithstanding the genius of Ericsson, however, engines of this type did not prove commercially successful on a large scale, and in subsequent decades the hot-air motors constructed for practical purposes seldom exceeded one horse-power. Such small engines as these are comparatively efficient and absolutely safe, and they are thoroughly adapted for such domestic purposes as light pumping.

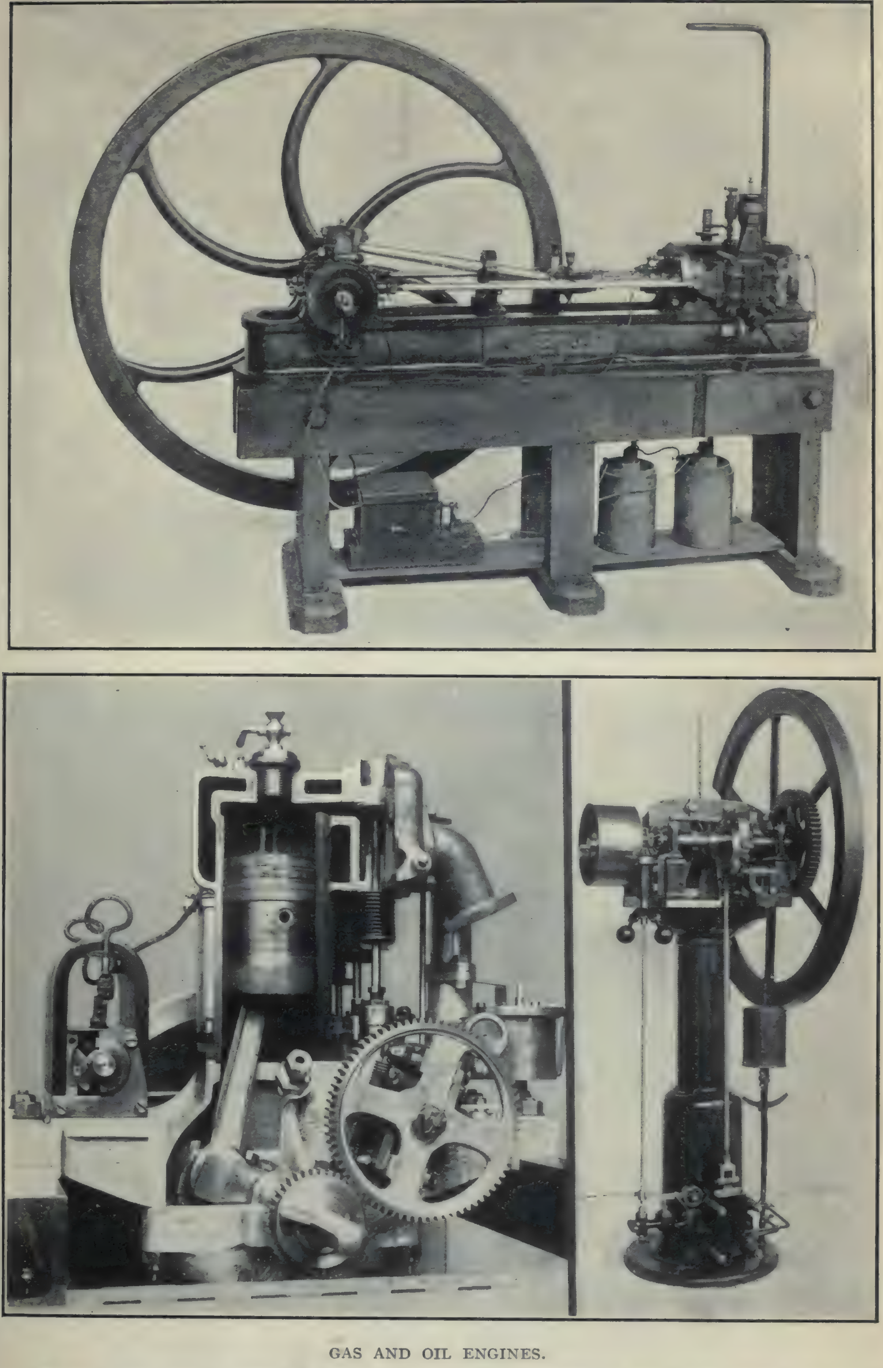
The great difficulty with all these engines operated with heated air has been, as already suggested, that their efficiency of action is limited by the difficulties incident to applying high temperatures to large masses of the gas. There is, however, no objection to the superheating of small quantities of gas, and it was early suggested that this might be accomplished by exploding a gaseous mixture within a cylinder. It was observed by the experimenters of the seventeenth century that an ordinary gun constitutes virtually an internal-combustion engine; and such experimenters as the Dutchman Huyghens, and the Frenchmen Hautefeuille and Papin, attempted to make practical use of the power set free by the explosion of gunpowder, their experiments being conducted about the years 1678 to 1689. Their results, however, were not such as to give them other than an historical interest. About a century later, in 1794, the Englishman Robert Street suggested the use of inflammable gases as explosives, and ever since that time there have been occasional experimenters along that line. In 1823 Samuel Brown introduced a vacuum gas engine for raising water by atmospheric pressure. The first fairly practical gas engine, however, was that introduced by J. J. E. Lenoir, who in 1850 proposed an engine working with a cycle resembling that of a steam engine. His engine patented in 1860 proved to be a fairly successful apparatus. This engine of Lenoir prepared the way for gas engines that have since become so enormously important. Its method of action is this:

"To start the engine, the fly-wheel is pulled round, thus moving the piston, which draws into the cylinder a mixture of gas and air through about half its stroke; the mixture is then exploded by an electric spark, and propels the piston to the end of its stroke, the pressure meanwhile falling, by cooling and expansion, to that of the atmosphere when exhaust takes place. In the return stroke the process is repeated, the action of the engine resembling that of the double-acting steam engine, and having a one-stroke cycle. The cylinder and covers are cooled by circulating water. The firing electricity was supplied by two Bunsen batteries and an induction coil, the circuit being completed at the right intervals by contact pieces on an insulating disc on the crank-shaft; the ignition spark leaped across the space between two wires carried about one-sixth of an inch apart in a porcelain holder."

In 1865 Mons. P. Hugon patented an engine similar to that of Lenoir, except that ignition was accomplished by an external flame instead of by electricity. The ignition flame was carried to and fro in a cavity inside a slide valve, moved by a cam so as to get a rapid cut-off, and permanent lights were maintained at the ends of the valve to re-light the flame-ports after each explosion. The gas was supplied to the cylinder by rubber bellows, worked by an eccentric on the crank-shaft. This engine could be operated satisfactorily, except as to cost, but the heavy gas consumption made it uneconomical.

An important improvement in this regard was introduced by the Germans, Herrn. E. Langen and N. A. Otto, who under patents bearing date of 1866 introduced a so-called "free" piston arrangement—that is to say an arrangement by which the piston depends for its action partly upon the momentum of a fly-wheel. This principle had been proposed for a gas engine as early as 1857, but the first machine to demonstrate its feasibility was that of Langen and Otto. Their engine greatly decreased the gas consumption and hence came to be regarded as the first commercially successful gas engine. It was, however, noisy and limited to small sizes. The cycle of operations of an engine of this type is described as follows:

"(a) The piston is lifted about one-tenth of its travel by the momentum of the fly-wheel, thus drawing in a charge of gas and air.



GAS AND OIL ENGINES.

Lower right-hand figure, a very early type of commercially successful gas engine. It has a "free" piston, an arrangement that was first proposed for a gas engine in 1857, but only brought into practical form by Langen & Otto under their patent of 1866. Upper figure, the gas engine patented by Lenoir in 1860, one of the very first practically successful engines. Lower left-hand figure, a sectional view of a modern gas engine of the type used as the motor of the automobile.

"(b) The charge is ignited by flame carried in by a slide valve.

"(c) Under the impulse of the explosion, the piston shoots upward nearly to the top of the cylinder, the pressure in which falls by expansion to about 4 lbs. absolute, while absorbing the energy of the piston.

"(d) The piston descends by its own weight and the atmospheric pressure, and in doing so causes a roller-clutch on a spur-wheel gearing with a rack on the piston-rod to engage, so that the fly-wheel shaft shall be driven by the piston; during this down-stroke the pressure increases from 4 lbs. absolute to that of the atmosphere, and averages 7 lbs. per square inch effective throughout the stroke.

"(e) When the piston is near the bottom of the cylinder, the pressure rises above atmospheric, and the stroke is completed by the weight of the piston and rack, and the products of combustion are expelled.

"(f) The fly-wheel now continues running freely till its speed, as determined by a centrifugal governor, falls below a certain limit when a trip gear causes the piston to be lifted the short distance required to recommence the cycle.

"Ignition is performed by an external gas jet, near a pocket in the slide valve by which the charge is admitted; this pocket carries flame to the charge, thus igniting it without allowing any escape. The valve also connects the interior of the cylinder with the exhaust pipe, and a valve in the latter controlled by the governor throttles the discharge, and so defers the next stroke until the speed has fallen below normal. To run the engine empty about four explosions per minute are necessary, and at full power 30 to 35 are made, so that about 28 explosions per minute are available for useful work under the control of the governor."

The definitive improvement in this gas engine was introduced in 1876 by Dr. N. A. Otto, when he compressed the explosive mixture in the working cylinder before igniting it. This expedient—so all-important in its results—had been suggested by William Barnett in 1838, but at that time gas engines were not sufficiently developed to make use of the idea. Now, however, Dr. Otto demonstrated that by compressing the gas before exploding it a much more diluted mixture can be fired, and that this gives a quieter explosion, and a more sustained pressure during the working stroke, while as the engine runs at a high speed the fly-wheel action is generally sufficient to correct the fluctuations arising from there being but one explosion for four strokes of the piston.

In this perfected engine, then, the method of operation is as follows:

The piston is pulled forward with the application of some outside force, which in practice is supplied by the inertia of the fly-wheel, or in starting the engine by the action of a crank with which every user of an automobile is familiar. In being pulled forward, the piston draws gas into the cylinder; as the piston returns, this gas is compressed; the compressed gas, constituting an explosive mixture, is then ignited by a piece of incandescent metal or by an electric spark; the exploding gas expands, pushing the piston forward, this being the only thrust during which work is done; the returning piston expels the expanded gas, completing the cycle. Thus there are three ineffective piston thrusts to one effective thrust. Nevertheless, the engine has proved a useful one for many purposes.

This so-called Otto cycle has been adopted in almost all gas and oil engines, the later improvements being in the direction of still higher compression, and in the substitution of lift for slide valves. There has been a steady increase in the size and power of such engines, the large ones usually introducing two or more working cylinders so as to secure uniform driving. Cheap forms of gas have been employed such as those made by decomposing water by incandescent fuel, and it has been proved possible thus to operate gas-power plants on a commercial scale in competition with the most economical steam installations.

A practical modification of vast importance was introduced when it was suggested that a volatile oil be employed to supply the gas for operation in an internal combustion engine. There was no new principle involved in this idea, and the Otto cycle was still employed as before; but the use of the volatile oil—either a petroleum product or alcohol—made possible the compact portable engine with which everyone is nowadays familiar through its use in automobiles and motor boats. The oil commonly used is gasoline which is supplied to the cylinder through a so-called carburettor in which the vapors of gasoline are combined with ordinary air to make an explosive mixture. The introduction of this now familiar type of motor is to a large extent due to

Herr G. Daimler, who in 1884 brought out a light and compact high-speed oil engine. About ten years later Messrs. Panhard and Levassor devised the form of motor which has since been generally adopted. Few other forms of mechanisms are better known to the general public than the oil engine with its two, four, six, or even eight cylinders, as used in the modern automobile. As everyone is aware, it furnishes the favorite type of motor, combining extraordinary power with relative lightness, and making it feasible to carry fuel for a long journey in a receptacle of small compass.

With the gas engines a complication arises precisely opposite to that which is met with in the case of the cylinder of the steam engine—the tendency, namely, to overheating of the cylinder. To obviate this it is customary to have the cylinder surrounded by a water jacket, though air cooling is used in certain types of machines. About fifty per cent. of the total heat otherwise available is lost through this unavoidable expedient.

The rapid introduction of the gas engine in recent years suggests that this type of engine may have a most important future. It has even been predicted that within a few years most trans-Atlantic steamers will be equipped with this type of engine, producing their own gas in transit. It is possible, then, that through this medium the old piston-and-cylinder engine may retain its supremacy, as against the turbine. For the moment, at any rate, the gas engine is gaining popularity, not merely in its application to the automobile, but for numerous types of small stationary engines as well.

In this connection it will be interesting to quote the report of the Special Agent of the Twelfth Census of the United States, as showing the status of gas engines and steam engines in the year 1902.

"The decade between 1890 and 1900," he says, "was a period of marked development in the use of gas engines, using that term to denote all forms of internal combustible engines, in which the propelling force is the explosion of gaseous or vaporous fuel in direct contact with a piston within a closed cylinder. This group embraces those engines using ordinary illuminating gas, natural gas, and gas made in special producers installed as a part of the power plant, and also vaporised gasoline or kerosene. This form of power for the first time is an item of consequence in the returns of the present census, and the very large increase in the horse-power in 1900 as compared with 1890 indicates the growing popularity of this class of motive power.

"In 1890 the number of gas engines in use in manufacturing plants was not reported, but their total power amounted to only 8,930 horse-power, or one-tenth of one per cent of the total power utilized in manufacturing operations. In 1900, however, 14,884 gas engines were reported, with a total of 143,850 horse-power, or 1.3 per cent of the total power used for manufacturing purposes. This increase from 8,930 horse-power to 143,850 horse-power, a gain of 134,920 horse-power, is proportionately the largest increase in any form of primary power shown by a comparison of the figures of the

Eleventh and Twelfth censuses, amounting to 1,510.9 per cent.

"Within the past decade, and more particularly during the past five years, there has been a marked increase in the use of this power in industrial establishments for driving machinery, for generating electricity, and for other kindred uses. At the same time, internal-combustion engines have increased in popularity for uses apart from manufacturing, and the amount of this kind of power in use for all purposes in 1900 was, doubtless, very much larger than indicated by the figures relating to manufacturing plants alone.

"The average horse-power per gas engine in 1900 was 9.7 horse-power. There are no available statistics upon which to base a comparison of this average with the average for 1890, but it is doubtful if there has been any very material change in ten years; for while gas engines are built in much larger sizes than ever before, there has been also a great increase in the number of small engines for various purposes.

"The large increase in the use of internal-combustion engines has been due to the rapid improvements that have been made in them, their increased efficiency and economy, their decreased cost, and the wider range of adaptability that has been made practicable.

"Steam still continues to be preeminently the power of greatest importance, and the census returns indicate that the proportion of steam to the total of all powers has increased very largely in the past thirty years. In 1870 steam furnished 1,215,711 horse-power, or 51.8 per cent of a total of 2,346,142; in 1880 the amount of steam power used was 2,185,458 horse-power out of a total of 3,410,837, or 64.1 per cent; in 1890 out of an aggregate of 5,954,655 horse-power, 4,581,595, or 76.9 per cent was steam; while in 1900 steam figured to the extent of 8,742,416 horse-power, or 77.4 per cent, in a total of 11,300,081. This increase in thirty years, from 51.8 per cent to 77.4 per cent of the total power, shows how much more rapidly the use of steam power has increased than other primary sources of power.

"The tendency toward larger units in the use of steam power is shown inadequately by the increase in the average horse-power per engine from 39 horse-power in 1880, to 51 horse-power in 1890, and 56 horse-power in 1900.

"The tendency toward great operations which has been such a conspicuous feature of industrial progress during the past ten years, has shown itself strikingly in the use of units of larger capacity in nearly every form of machinery, and nowhere has this tendency been more marked than in the motive power by which the machinery is driven. At the same time there has been an increase in the use of small units, which tends to destroy the true tendency in steam engineering in these statistics. For example, a steam plant consisting of one or more units of several thousand horse-power may also embrace a number of small engines of only a few horse-power each, the use of which is necessitated by the magnitude of the plant, for the operation of mechanical stokers, the driving of draft fans, coal and ash conveyors, and other work requiring power in small units. On this account the average horse-power of steam engines in use at different census periods fails to afford a true basis for measuring progress toward larger units during the past ten years.

"Developments of the past few years in the distribution of power by the use of electric motors have served to accelerate the tendency toward larger steam units and the elimination of small engines in large plants and to change completely the conditions just described. For example: In one of the largest power plants in the world, which is now being installed, all the stokers, blowers, conveyors, and other auxiliary machinery are to be driven by electric motors. Such rapidly changing conditions tend to invalidate any comparisons of statistical averages deduced from figures for periods even but a few years apart.

"Comparison of two important industries will illustrate the foregoing. The average horse-power of the steam engine used in the cotton mills of the United States in 1890 was 198, and in 1900 it was 300.

"In the iron and steel industry the average horse-power per engine in 1890 was 171, and in 1900 it was 235. In the cotton mills the use of single large units of motive power, with few auxiliary engines of small capacity, gives the largest horse-power per engine of any industry; while in the iron and steel industry the average of the motive power proper, although probably larger than in the manufacture of cotton goods, is reduced by the large number of small engines which are used for auxiliary purposes in every iron and steel plant."

It will be understood that the object of exploding the mixed gases in the oil engine is to produce sudden heating of the entire gas. There is no reason whatever for introducing the gasoline beyond this. Could a better method of heating air be devised, the oil might be entirely dispensed with, and the safety of the apparatus enhanced, as well as the economy of operation. Efforts have been made for fifty years to construct a hot-air engine that would compete with steam successfully. In the early fifties, as already noted, Ericsson showed the feasibility of substituting hot air for steam, but although he constructed large engines, their power was so slight that he was obliged to give up the idea of competing with steam, and to use his engines for pumping where very small power was required.

The great difficulty was that it was not found practicable to heat the air rapidly. All subsequent experimenters have met with the same difficulty until somewhat recently. It is now claimed, however, that a means has been found of rapidly heating the air, and it is even predicted that the hot-air engine will in due course entirely supersede the steam engine. Mr. G. Emil Hesse, in an article in *The American Inventor*, for April 15, 1905, describes a Svea caloric engine as having successfully solved the problem of rapidly heating air. The methods consist in breaking up the air into thin layers and passing it over hot plates, where it rapidly absorbs heat. It passes from the heater to the power cylinder which resembles the cylinder of a steam engine; thence after expanding and doing its work it is exhausted into the atmosphere. Large engines may use the same air over and over again under pressure of one hundred pounds per square inch, alternately heating and cooling it. A six horse-power engine of this type is said to have a cylinder four and one-half inches in diameter and a stroke of four and seven-eighth inches, and makes four hundred and fifty revolutions per minute. The heater is twenty inches in diameter, sixteen inches long, and has a heating surface of sixty square feet. The total weight of heater and engine complete is four hundred pounds for a half horse-power Ericsson engine.

"The Svea heater," says Mr. Hesse, "absorbs the heat as perfectly as an ordinary steam boiler, and the heat-radiating surface of both heater and engine is not larger than that of a steam plant of the same power, thereby placing the two motors on the same basis, as far as the utilization of the heat in the fuel itself is concerned.

"The advantage which every hot-air engine has over the steam engine is the amount of heat saved in the vaporization of the water. It is now well known that one gas is as efficient as another for the conversion of heat into power. Air and steam at 100° C. are consequently on the same footing and ready to be superheated. The amount of heat required to bring the two gases to this temperature is, however, very different.

"With an initial temperature of 10° C. for both air and water, we find that one kilogram of steam requires $90 + 537 = 627$ thermal units, and one kilogram of air $0.24 \times 90 = 21.6$ thermal units. Some heat is recovered if the feed water is heated and the steam condensed, but the difference is still so great as to altogether exclude steam as a competitor, provided air can be as readily handled.

"Having now the means to rapidly heat the air, the outlook for the external-combustion engine is certainly very promising.

"The saving of more than half the coal now used by the steam engine will be of tremendous importance to the whole world."

To what extent this optimistic prediction will be verified is a problem for the future to decide.

VIII

THE SMALLEST WORKERS

IN our studies of the steam engine and gas engine we have been concerned with workers of infinitesimal size. Yet, if we are to believe the reports of the modern investigator, the molecules of steam or of ignited gas are small only in a relative sense, and there is a legion of workers compared with which the molecules are really gigantic in size. These workers are the atoms, and the yet more minute particles of which, according to the most recent theories, they are themselves composed.

These smallest conceivable particles, the constituents of the atoms, are called electrons. They are a discovery of the physicists of the most recent generation. According to the newest theories they account for most—perhaps for all—of the inter-molecular and inter-atomic forces; they are indeed the ultimate repositories of those stores of energy which are known to be contained in all matter. The theories are not quite as fully developed as could be wished, but it would appear that these minutest particles, the electrons, are the essential constituents of the familiar yet wonderful carrier of energy which we term electricity. In considering the share of electricity in the world's work, therefore, we shall do well at the outset to put ourselves in touch with recent views as to the nature of this most remarkable of workers.

On every side in this modern world we are confronted by this strange agent, electricity. The word stares us in the face on every printed page. The thing itself is manifest in all departments of our every-day life. You go to your business in an electric car; ascend to your office in an electric elevator; utilize electric call-bells; receive and transmit messages about the world and beneath the sea by electric telegraph. Your doctor treats you with an electric battery. Your dentist employs electric drills and electric furnaces. You ride in electric cabs; eat food cooked on electric stoves; and read with the aid of electric light. In a word, the manifestations of electricity are so obvious on every side that there can be no challenge to the phrasing which has christened this the Age of Electricity.

But what, then, is this strange power that has produced all these multifarious results? It would be hard to propound a scientific query that has been more variously answered. Ever since the first primitive man observed the strange effect produced by rubbing a piece of amber, thoughtful minds must have striven to explain that effect. Ever since the eighteenth-century scientist began his more elaborate studies of electricity, theories in abundance have been propounded. And yet we are not quite sure that even the science of to-day can give a correct answer as to the nature of electricity. At the very least, however, it is able to give some interesting suggestions which seem to show that we are in a fair way to solve this world-old mystery. And, curiously enough, the very newest explanations are not so very far away from some eighteenth-century theories which for a long time were looked at askance if not altogether discarded. In particular, the theory of Benjamin Franklin, which considered electricity as an immaterial fluid bearing certain curious relations to tangible matter, is found to serve singularly well as an aid to the interpretation of the very newest experiments.

FRANKLIN'S ONE-FLUID THEORY

Such being the case, we must consider this theory of Franklin's somewhat in detail. Perhaps we cannot do better than state the theory in the words of the celebrated physicist, Dr. Thomas Young, as given in his work on natural philosophy, published in 1807. By quoting from this old work we shall make sure that we are not reading any modern interpretations into the theory. "It is supposed," says Young, "that a peculiar ethereal fluid pervades the pores, if not the actual substance of the earth and of all other material bodies, passing through them with more or less facility, according to their different powers of conducting it; that particles of this fluid repel each other, and are attracted by particles of common matter; that particles of common matter also repel each other; and that these attractions and repulsions are equal among themselves, and vary inversely as to squares of the distances of the particles. The effects of this fluid are distinguished from those of all other substances by an attractive or repulsive quality, which it appears to communicate to different bodies, and which differs in general from other attractions and repulsions by its immediate diminution or cessation when the bodies, acting on each other, come into contact, or are touched by other bodies. . . . In general, a body is said to be electrified when it contains, either as a whole or in any of its parts, more or less of the electric fluid than is natural to it . . . In this common neutral state of all bodies, the electrical fluid, which is everywhere present, is so distributed that the various forces hold each other exactly in equilibrium and the separate results are destroyed, unless we choose to consider gravitation itself as arising from a comparatively slight inequality between the electrical attractions and repulsions."

The salient and striking feature of this theory, it will be observed, is that the electrical fluid, under normal conditions, is supposed to be incorporated everywhere with the substance of every material in the world. It will be observed that nothing whatever is postulated as to the nature or properties of this fluid beyond the fact that its particles repel each other and are attracted by the particles of common matter; it being also postulated that the particles of common matter likewise repel each other under normal conditions.

At the time when Franklin propounded his theory, there was a rival theory before the world, which has continued more or less popular ever since, and which is known as the two-fluid theory of electricity. According to this theory, there are two uncreated and indestructible fluids which produce electrical effects. One fluid may be called positive, the other negative. The particles of the positive fluid are mutually repellent, as also are the particles of the negative fluid, but, on the other hand, positive particles attract and are attracted by negative particles. We need not further elaborate the details of this two-fluid theory, because the best modern opinion considers it less satisfactory than Franklin's one-fluid theory. Meantime, it will be observed that the two theories have much in common; in particular they agree in the essential feature of postulating an invisible something which is not matter, and which has strange properties of attraction and repulsion.

These properties of attraction and repulsion constituted in the early day the only known manifestations of electricity; and the same properties continue to hold an important place in modern studies of the subject. Electricity is so named simply because amber—the Latin *electrum*—was the substance which, in the experience of the ancients, showed most conspicuously the strange property of attracting small bodies after being rubbed. Modern methods of developing electricity are extremely diversified, and most of them are quite unsuggestive of the rubbing of amber; yet nearly all the varied manifestations of electricity are reducible, in the last analysis, to attractions and repulsions among the particles of matter.

As to the alleged immaterial fluids which, according to the theories just mentioned, make up the real substance of electricity, it was perfectly natural that they should be invented by the physicists of the elder day. All the conceptions of the human mind are developed through contact with the material world; and it is extremely difficult to get away, even in theory, from tangible realities. When the rubbed amber acquires the property of drawing the pith ball to it, we naturally assume that some change has taken place in the condition of the amber; and since the visible particles of amber appear to be unchanged—since its color, weight, and friability are unmodified—it seems as if some immaterial quality must have been added to, or taken from it. And it was natural for the eighteenth-century physicist to think of this immaterial something as a fluid, because he was accustomed to think of light, heat, and magnetism as being also immaterial fluids. He did not know, as we now do, that what we call heat is merely the manifestation of varying "modes" of motion among the particles of matter, and that what we call light is not a thing *sui generis*, but is merely our recognition of waves of certain length in the all-pervading ether. The wave theory of light had, indeed, been propounded here and there by a philosopher, but the theory which regarded light as a corpuscular emanation had the support of no less an authority than Sir Isaac Newton, and he was a bold theorist that dared challenge it. When Franklin propounded his theory of electricity, therefore, his assumption of the immaterial fluid was thoroughly in accord with the physical doctrines of the time.

MODERN VIEWS

But about the beginning of the nineteenth century the doctrine of imponderable fluids as applied to light and heat was actively challenged by Young and Fresnel and by Count Rumford and Humphry Davy and their followers, and in due course the new doctrines of light and heat were thoroughly established. In the light of the new knowledge, the theory of the electric fluid or fluids seemed, therefore, much less plausible. Whereas the earlier physicists had merely disputed as to whether we must assume the existence of two electrical fluids or of only one, it now began to be questioned whether we need assume the existence of any electrical fluid whatever. The physicists of about the middle of the nineteenth century developed the wonderful doctrine of conservation of energy, according to which one form of force may be transformed into another, but without the possibility of adding to, or subtracting from, the original sum total of energy in the universe. It became evident that electrical force must conform to this law. Finally, Clerk-Maxwell developed his wonderful electromagnetic theory, according to which waves of light are of electrical origin. The work of Maxwell was followed up by the German Hertz, whose experiments produced those electromagnetic waves which, differing in no respect except in their length from the waves of light, have become familiar to everyone through their use in wireless telegraphy. All these experiments showed a close relation between electrical phenomena, and the phenomena of light and of radiant heat, and a long step seemed to be taken toward the explanation of the nature of electricity.

The new studies associated electricity with the ether, rather than with the material substance of the electrified body. Many experiments seemed to show that electricity in motion traverses chiefly the surface of the conductor, and it came to be believed that the essential feature of the "current" consists of a condition of strain or stress in the ether surrounding a conductor, rather than of any change in the conductor itself. This idea, which is still considered valid, has the merit of doing away with the thought of action at a distance—the idea that was so repugnant to the mind of Faraday.

So far so good. But what determines the ether strain? There is surely *something* that is not matter and is not ether. What is this something? The efforts of many of the most distinguished experimenters have in recent years been directed toward the solution of that question; and these efforts, thanks to the new methods and new discoveries, have met with a considerable measure of success. I must not attempt here to follow out the channels of discovery, but must content myself with stating briefly the results. We shall have occasion to consider some further details as to the methods in a later chapter.

Briefly, then, it is now generally accepted, at least as a working hypothesis, that every atom of matter—be it oxygen, hydrogen, gold, iron, or what not—carries a charge of electricity, which is probably responsible for all the phenomena that the atom manifests. This charge of electricity may be positive or negative, or it may be neutral, by which is meant that the positive and negative charges may just balance. If the positive charge has definite carriers, these are unknown except in association with the atom itself; but the negative charge, on the other hand, is carried by minute particles to which the name electron (or corpuscle) has been given, each of which is about one thousand times smaller than a hydrogen atom, and each of which carries uniformly a unit charge of negative electricity.

Electrons are combined, in what may be called planetary systems, in the substance of the atom; indeed, it is not certain that the atom consists of anything else but such combinations of electrons, held together by the inscrutable force of positive electricity. Some, at least, of the electrons within the atom are violently active—perhaps whirling in planetary orbits,—and from time to time one or more electrons may escape from the atomic system. In thus escaping an electron takes away its charge of negative electricity, and the previously neutral atom becomes positively electrified. Meanwhile the free electron may hurtle about with its charge of negative electricity, or may combine with some neutral atom and thus give to that neutral atom a negative charge. Under certain conditions myriads of these electrons, escaped thus from their atomic systems, may exist in the free state. For example, the so-called *beta* (β) rays of radium and its allies consist of such electrons, which are being hurtled off into space with approximately the speed of light. The cathode rays, of which we have heard so much in recent years, also consist of free electrons.

But, for that matter, all currents of electricity whatever, according to this newest theory, consist simply of aggregations of free electrons. According to theory, if the electrons are in uniform motion they produce the phenomena of constant currents of electricity; if they move non-uniformly they produce electromagnetic phenomena (for example, the waves used in wireless telegraphy); if they move with periodic motion they produce the waves of light. Meanwhile stationary aggregations of electrons produce the so-called electrostatic phenomena. All the various ether waves are thus believed to be produced by changes in the motions of the electrons. A very sudden stoppage, such as is produced when the cathode ray meets an impassable barrier, produces the *X*-ray.

With these explanations in mind, it will be obvious how closely this newest interpretation of electricity corresponds in its general features with the old one-fluid theory of Franklin. The efforts of the present-day physicist have resulted essentially in an analysis of Franklin's fluid, which gives to this fluid an atomic structure. The new theory takes a step beyond the old in suggesting the idea that the same particles which make up the electric fluid enter also into the composition—perhaps are the sole physical constituents—of every material substance as well. But while the new theory thus extends the bounds of our vision, we must not claim that it fully solves the mystery. We can visualize the ultimate constituent of electricity as an electron one thousand times smaller than the hydrogen atom, which has mass and inertia, and which possesses powers of attraction and repulsion. But as to the actual nature of this ultimate particle we are still in the dark. There are, however, some interesting theories as to its character, which should claim at least incidental attention.

We have all along spoken of the electron as an exceedingly minute particle, stating indeed, that in actual size it is believed to be about one thousand times smaller than the hydrogen atom, which hitherto had been considered the smallest thing known to science. But we have now to offer a seemingly paradoxical modification of this statement. It is true that in *mass* or weight the electron is a thousand times smaller than the hydrogen atom, yet at the same time it may be conceived that the limits of space which the electron occupies are indefinitely large. In a word, it is conceived (by Professor J. J. Thomson, who is the chief path-breaker in this field) that the electron is in reality a sort of infinitesimal magnet, having two poles joined by lines or tubes of magnetic force (the so-called Faraday tube), which lines or tubes are of indefinite number and extent; precisely as, on a large scale, our terrestrial globe is such a magnet supplied with such an indefinite magnetic field. That the mass of the electron is so infinitesimally small is explained on the assumption that this mass is due to a certain amount of universal ether which is bound up with the tubes where they are thickest; close to the point in space from which they radiate, which point in space constitutes the focus of the tangible electron.

It will require some close thinking on the part of the reader to gain a clear mental picture of this conception of the electron; but the result is worth the effort. When you can clearly conceive all matter as composed of electrons, each one of which cobwebs space with its system of magnetic tubes, you will at least have a tangible picture in mind of a possible explanation of the forces of cohesion and gravitation—in fact, of all the observed cases of seeming action at a distance. If at first blush the conception of space as filled with an interminable meshwork of lines of force seems to involve us in a hopeless mental tangle, it should be recalled that the existence of an infinity of such magnetic lines joining the poles of the earth may be demonstrated at any time by the observation of a compass, yet that these do not in any way interfere with the play of other familiar forces. There is nothing unthinkable, then, in the supposition that there are myriads of minor magnetic centres exerting lesser degrees of force throughout the same space.

All that can be suggested as to the actual nature of the Faraday tubes is that they perhaps represent a condition of the ether. This, obviously, is heaping hypothesis upon hypothesis. Yet it should be understood that the hypothesis of the magnetic electron as the basis of matter, has received an amount of experimental support that has raised it at least to the level of a working theory. Should that theory be demonstrated to be true, we shall apparently be forced to conclude not merely that electricity is present everywhere in nature, but that, in the last analysis, there is absolutely no tangible thing other than electricity in all the universe.

HOW ELECTRICITY IS DEVELOPED

Turning from this very startling theoretical conclusion to the practicalities, let us inquire how electricity —which apparently exists, as it were, in embryo everywhere—can be made manifest. In so doing we shall discover that there are varying types of electricity, yet that these have a singular uniformity as to their essential properties. As usually divided—and the classification answers particularly well from the standpoint of the worker—electricity is spoken of as either statical or dynamical. The words themselves are suggestive of the essential difference between the two types. Statical electricity produces very striking manifestations. We have already spoken of it as theoretically due to the conditions of the electrons at rest. It must be understood, however, that the statical electricity will, if given opportunity, seek to escape from any given location to another location, under certain conditions, somewhat as water which is stored up in a reservoir will, when opportunity offers, flow down to a lower level. The pent-up static electricity has, like the water in the reservoir, a store of potential energy. The physicist speaks of it as having high tension. In passing to a condition of lower tension, the statical electricity may give up a large portion of its energy.

If, for example, on a winter day in a cold climate, you walk briskly along a wool carpet, the friction of your feet with the carpet generates a store of statical electricity, which immediately passes over the entire surface of your body. If now you touch another person or a metal conductor, such as a steam radiator or a gas pipe, a brilliant spark jumps from your finger, and you experience what is spoken of as an electrical shock. If the day is very cold, and the air consequently very dry, and if you will take pains to rub your feet vigorously or slide along the carpet, you may light a gas jet with the spark which will spring from your finger to the tip of the jet, provided the latter is of metal or other conducting substance; and even if you attempt to avoid the friction between your feet and the carpet as much as possible, you may be constantly annoyed by receiving a shock whenever you touch any conductor, since, in spite of your efforts, the necessary amount of friction sufficed to generate a store of statical electricity.

An illustration of the development of this same form of electricity, on a large scale, is supplied by the familiar statical machine, which consists of a large circle of glass, so adjusted that it may be revolved rapidly against a suitable friction producer. With such a machine a powerful statical current is produced, capable of generating a spark that may be many inches or even several feet in length,—a veritable flash of lightning. It is with such a supply of electricity conducted through a vacuum tube that the cathode ray and the Roentgen ray are produced.

Such effects as this suggest considerable capacity for doing work. Yet in reality, notwithstanding the very sporadical character of the result, the quantity of electricity involved in such a statical current may be very slight indeed. Even a lightning flash is held to represent a comparatively small amount of electricity. Faraday calculated that the amount of electricity that could be generated from a single drop of water, through chemical manipulation, would suffice to supply the lightning for a fair-sized thunder-storm. Nevertheless the destructive work that may be done by a flash of lightning may be considerable, as everyone is aware. But, on the other hand, while the visible effect of a stroke of lightning on a tree trunk, for example, makes it seem a powerful agency, yet the actual capacity to do work—the power to move considerable masses of matter—is extremely limited. The effect on a tree trunk, it will be recalled, usually consists of nothing more than the stripping off of a channel of bark. In other words, the working energy contained in a seemingly powerful supply of statical electricity commonly plays but an insignificant part.

The working agent, and therefore the form of electricity which concerns us in the present connection, is the dynamical current. This may be generated in various ways, but in practice these are chiefly reducible to two. One of these depends upon chemical action, the other upon the inter-relations of mechanical motion and magnetic lines of force. A common illustration of the former is supplied by the familiar voltaic or galvanic battery. The electromagnetic form has been rendered even more familiar in recent times by the dynamo. This newest and most powerful of workers will claim our attention in detail in the succeeding chapter. Our present consideration will be directed to the older method of generating the electric current as represented by the voltaic cell.

THE WORK OF THE DYNAMICAL CURRENT

Let us draw our illustration from a familiar source. Even should your household otherwise lack electrical appliances, you are sure to have an electric call-bell. The generator of the electric current, which is stored away in some out-of-the-way corner, is probably a small so-called "dry-cell" which you could readily carry around in your pocket; or it may consist of a receptacle holding a pint or two of liquid in which some metal plates are immersed. Such an apparatus seems scarcely more than a toy when we contrast it with the gigantic dynamos of the power-house; yet, within the limits of its capacities, one is as surely a generator of electricity as the other. If we are to accept the latest theory, the electrical current which flows from this tiny cell is precisely the same in kind as that which flows from the five-thousand-horse-power dynamo. The difference is only one of quantity.

To understand the operation of this common household appliance we must bear in mind two or three familiar experimental facts in reference to the action of the voltaic cell. Briefly, such a cell consists of two plates of metal—for example, one of copper and the other of zinc—with a connecting medium, which is usually a liquid, but which may be a piece of moistened cloth or blotting-paper. So long as the two plates of metal are not otherwise connected there is no electricity in evidence, but when the two are joined by any metal conductor, as, for example, a piece of wire—thus, in common parlance, "completing the circuit"—a current of electricity flows about this circuit, passing from the first metal plate to the second, through the liquid and back from the second plate to the first through the piece of wire. The wire may be of any length. In the case of your call-bell, for example, the wire circuit extends to your door, and is there broken, shutting off the current.

When you press the button you connect the broken ends of the wire, thus closing the circuit, as the saying is, and the re-established current, acting through a little electromagnet, rings the bell. In another case, the wire may be hundreds of miles in length, to serve the purposes of the telegrapher, who transmits his message by opening and closing the circuit, precisely as you operate your door-bell. For long-distance telegraphy, of course, large cells are required, and numbers of them are linked together to give a cumulative effect, making a strong current; but there is no new principle involved.

The simplest study of this interesting mechanism makes it clear that the cell is the apparatus primarily involved in generating the electric current; yet it is equally obvious that the connecting wire plays an important part, since, as we have seen, when the wire is broken there is no current in evidence. Now, according to the electron theory, as previously outlined, the electric current consists of an actual flow along the wire of carriers of electricity which are unable to make their way except where a course is provided for them by what is called a conductor. Dry air, for example, is, under ordinary circumstances, quite impervious to them. This means, then, that the electrons flow freely along the wire when it is continuous, but that they are powerless to proceed when the wire is cut. When you push the button of your call-bell, therefore, you are virtually closing the switch which enables the electrons to proceed on their interrupted journey.

THEORIES OF ELECTRICAL ACTION

But all this, of course, leaves quite untouched the question of the origin of the electrons themselves. That these go hurtling from one plate or pole of the battery to the other, along the wire, we can understand at least as a working theory; that, furthermore, the electrons have their origin either in the metal plates or in the liquid that connects them, seems equally obvious; but how shall we account for their development? It is here that the chemist with his atomic theory of matter comes to our aid. He assures us that all matter consists in the last analysis of excessively minute particles, and that these particles are perpetually in motion. They unite with one another to form so-called molecules, but they are perpetually breaking away from such unions, even though they re-establish them again. Such activities of the atoms take place even in solids, but they are greatly enhanced when any substance passes from the solid into the liquid state.

When, for example, a lump of salt is dissolved in water, the atoms of sodium and of chlorine which joined together make up the molecules of salt are held in much looser bondage than they were while the salt was in a dry or crystalline form. Could we magnify the infinitesimal particles sufficiently to make them visible we should probably see large numbers of the molecules being dissociated, the liberated atoms moving about freely for an instant and then reuniting with other atoms. Thus at any given instant our solution of salt would contain numerous free *atoms* of sodium and of chlorine, although we are justified in thinking of this substance as a whole as composed of sodium-chlorine *molecules*. It is only by thus visualizing the activity of the atoms in a solution that we are able to provide even a thinkable hypothesis as to the development of electricity in the voltaic cell.

What puts us on the track of the explanation we are seeking is the fact that the diverse atoms are known to have different electrical properties. In our voltaic cell, for example, sodium atoms would collect at one pole and chlorine atoms at the other. Humphry Davy discovered this fact in the early days of electro-chemistry, just about a century ago. He spoke of the sodium atom as electro-positive, and of the chlorine atom as electro-negative, and he attempted to explain all chemical affinity as merely due to the mutual attraction between positively and negatively electrified atoms. The modern theorist goes one step farther, and explains the negative properties of the chlorine atom by assuming the presence of one negative electron or electricity in excess of the neutralizing charge. The assumption is, that the sodium atom has lost this negative electron and thus has become positively electrified. The chlorine atom, harboring the fugitive electron, becomes negatively electrified. Hence the two atoms are attracted toward opposite poles of the cell.

This disunion of atoms, be it understood, must be supposed to take place in the case of any solution of common salt, whether it rests in an ordinary cup or forms a part of the ocean. Here we have, then, material for the generation of the electrical current, if some means could be found to induce the chlorine atom to give up the surplus electron which from time to time it carries. And this means is provided when two pieces of metal of different kinds, united with a metal conductor, are immersed in the liquid. Then it comes to pass that the electrons associated with the chlorine atoms that chance to lie in contact with one of these plates of metal, find in this metal an avenue of escape. They rush off eagerly along the metal and the connecting wire, and in so doing establish a current which acts—if we may venture a graphic analogy from an allied field of physics—as a sort of suction, attracting other chlorine atoms from the body of the liquid against the metal plate that they also may discharge their electrons. In other words, the electrical current passes through the liquid as well as through the outside wire, thus completing the circuit.

According to this theory, then, the electrical energy in evidence in the current from the voltaic cell, is drawn from a store of potential energy in the atoms of matter composing the liquid in the cell. In practice, as is well known, the liquid used is one that affects one of the metal poles more actively than the other, insuring vigorous chemical activity. But the principle of atomic and electrical dissociation just outlined is the one involved, according to theory, in every voltaic cell, whatever the particular combination of metals and liquids of which it is composed. It should be added, however, that while we are thus supplied with a thinkable explanation of the origin of this manifestation of electrical energy, no explanation is forthcoming, here any more than in the case of the dynamo, as to why the electrons rush off in a particular direction and thus establish an electrical current. Perhaps we should recall that the very existence of this current has at times been doubted. Quite recently, indeed, it has been held that the seeming current consists merely of a condition of strain or displacement of the ether. But we are here chiefly concerned with the electron theory, according to which, as we have all along noted, the seeming current is an actual current; the ether strain, if such exists, being due to the passage of the electrons.

PRACTICAL USES OF ELECTRICITY

Various effects of the current of electrons have been hinted at above. Considered in detail, the possible ways in which these currents may be utilized are multifarious. Yet, they may be all roughly classified into three divisions as follows:

First, cases in which the current of electricity is used to transmit energy from one place to another, and reproduce it in the form of molar motion. The dynamo, in its endless applications, illustrates one phase of such transportation of energy; and the call-bell, the telegraph, and the telephone represent another phase. In one case a relatively large quantity of electricity is necessary, in the other case a small quantity; but the principle involved—that of electric and magnetic induction—is the same in each.

The second method is that in which the current, generated by either a dynamo or a battery of voltaic cells, is made to encounter a relatively resistant medium in the course of its flow along the conducting circuit. Such resistance leads to the production of active vibrations among the particles of the resisting medium, producing the phenomena of heat and, if the activity is sufficient, the phenomena of light also. It will thus appear that in this class of cases, as in the other, there is an actual re-transformation of electrical energy into the energy of motion, only in this case the motion is that of molecules and not of larger bodies. The principle is utilized in the electrical heater, with which our electric street-cars are commonly provided, and which is making its way in the household for purposes of general heating and of cooking. It is utilized also in various factories, where the very high degree of heat attainable with the electrical furnace is employed to produce chemical dissociation and facilitate chemical combinations. By this means, for example, a compound of carbon and silicon, which is said to be the hardest known substance, except the diamond, is produced in commercial quantities. A familiar household illustration of the use of this principle is furnished by the electric light. The carbon filament in the electric bulb furnishes such resistance to the electric current that its particles are set violently aquiver. Under ordinary conditions the oxygen of the air would immediately unite with the carbon particles, volatilizing them, and thus instantly destroying the filament; but the vacuum bulb excludes the air, and thus gives relative permanency to the fragile thread.

The third class of cases in which the electric current is commercially utilized is that in which the transformations it effects are produced in solutions comparable to those of the voltaic cell, the principles involved being those pointed out in the earlier part of the present chapter. By this means a metal may be deposited in a pure state upon the surface of another metal made to act as a pole to the battery; as, for example, when forks, spoons, and other utensils of cheap metals are placed in a solution of a silver compound, and thus electroplated with silver. To produce the powerful effects necessary in the various commercial applications of this principle, the poles of the voltaic cell—which cell may become in practice a large tank—are connected with the current supplied by a dynamo. Various chemical plants at Niagara utilize portions of the currents from the great generators there in this way. Another familiar illustration of the principle is furnished by the copper electroplates from which most modern books are printed.

It appears, then, that all the multifarious uses of electricity in modern life are reducible to a few simple principles of action, just as electricity itself is reduced, according to the analysis of the modern physicist, to the activities of the elementary electron. There is nothing anomalous in this, however, for in the last analysis the mechanical principles involved in doing all the world's work are few and relatively simple, however ingenious and relatively complex may be the appliances through which these principles are made available.

IX

MAN'S NEWEST CO-LABORER: THE DYNAMO

AS you stand waiting for your train at elevated or subway station you must have noticed the third rail. To outward appearance it is not different from the other rails. It seems a mere inert piece of steel. Yet you are well aware that a strange power abides there unseen—a power that pulls the train, and that lurks in hiding to strike a death-blow to any chance unfortunate whose foot or hand comes in contact with the rail. As the heavy train dashes up, dragged by this unseen power, probably you, in common with the rest of the world, have been led to remark, "Is it not marvelous?"

Marvelous it surely seems. Yet the cause of our astonishment is to be sought in the relative newness of the phenomena rather than in the nature of the phenomena themselves. At first glance it may seem that the intangible character of the electrical power gives it a unique claim on our wonderment. But a moment's reflection dispels this illusion. After all, electricity is no more intangible than heat. Neither the one nor the other can be seen or heard, but each alike may be felt. Yet we observe without astonishment a locomotive propelled by the power of heat—simply because the locomotive has become an old story. Again, electricity is far less intangible than gravitation. Not merely may electricity be felt, but it may be generated through transformation of other forms of energy; it may be stored away and measured; may be conducted at will through tortuous channels, or obstructed in its flight by the intervention of non-conductors. But gravitation submits to no such restrictions. It eludes all of our senses, and it absolutely disregards all barriers. To its catholic taste all substances are alike. It holds in bondage every particle of matter in the universe, and can enforce its influence over every kind of atom with an impartiality that is as astounding as it is inexorable. Moreover, this weird force, gravitation, has thus far evaded all man's efforts to classify or label it. No man has the slightest inkling as to what gravitation really is. If, as you glance at these lines, you should chance to release your hold and allow the volume to drop to the floor, you will have performed a miracle which no scientist in the world can even vaguely explain.

As regards our electric train, then, the fact that it stands there firmly, held fast to the rails by gravitation, is in reality as great and as inexplicable a marvel as the fact that the electric current gives it propulsion. Not only so, but the fact that the train goes forward of its own inertia, as we say, for a time after the current is shut off, presents to us yet another inexplicable marvel. It is a fundamental property of matter, we say, when once in motion to continue in motion until stopped by some counter-force; but that phrasing, expressive though it be of a fact upon which so many physical phenomena depend, is in no proper sense of the word an explanation.

Once for all, then, there is nothing unique, nothing preternaturally marvelous, about the phenomena of electricity. And indeed, it is interesting to note how quickly we become accustomed to these phenomena, and how little wonder they excite so soon as they cease to be novel. Even imaginative people have long since ceased to give thought to the trolley car; and within a week of the opening of New York's subway the average man came to regard it as much as a matter of course as if he had been accustomed to it from boyhood.

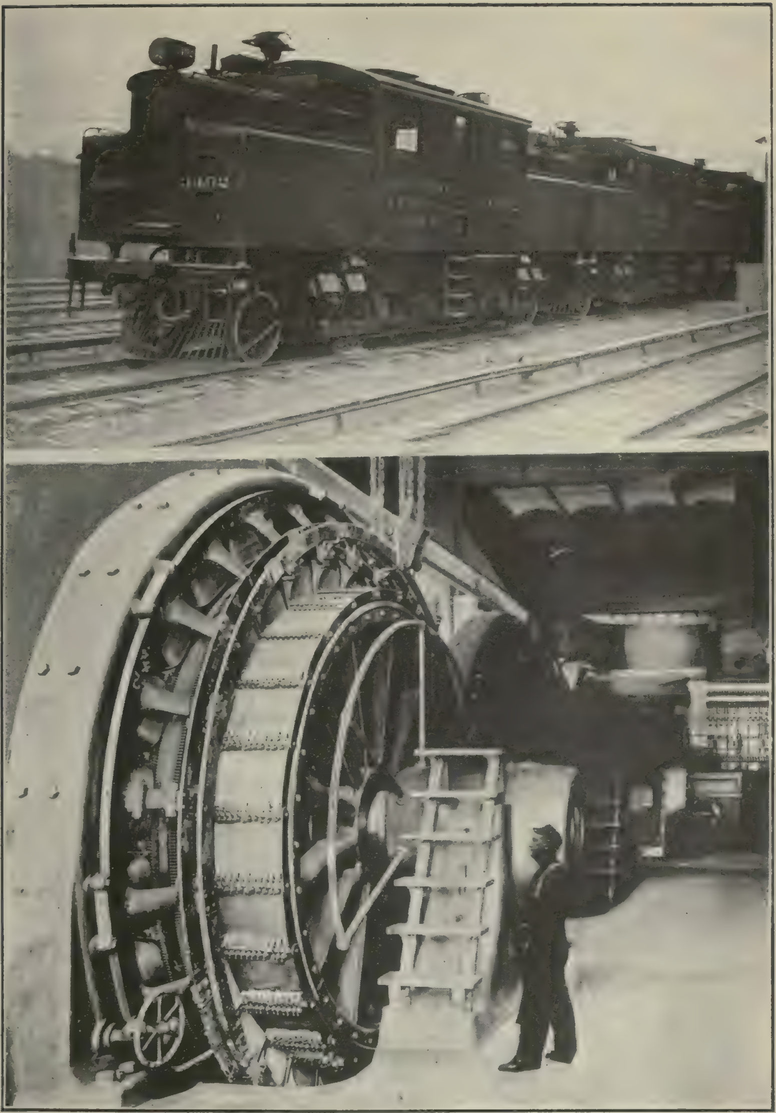
And yet, in another sense of the word, the electric motor is a wonderful contrivance. As an example of what man's ingenuity can accomplish toward transforming the powers of nature and adapting them to his own use, it is fully entitled to be called a marvel. Moreover, in the last analysis, we are as helpless to explain the nature of electricity as we are to explain the nature of gravitation. It is only the proximal phenomena of the electric current that can be explained. These phenomena, however, are full of interest. Let us examine them somewhat in detail, allowing them to lead us back from electric train to power-house and dynamo, and from dynamo as far toward the mystery of electric energy as present-day science can guide us.

THE MECHANISM OF THE DYNAMO

If we could look into the interior of a mechanism in connection with the trucks beneath the car, we should find an apparatus consisting essentially of coils of wire adjusted compactly about an axis, and closely fitted between the poles of a powerful electromagnet. These coils of wire constitute what is called an armature. When the current is switched on it passes through this armature, as well as through the electromagnet, and the mutual attractions and repulsions between the magnetic poles and the electric current in the coils of wire, cause the armature to revolve with such tremendous energy as to move the train—the motion of its axis being transmitted to the axle of the car-wheels by a simple gearing.

All this is simple enough if we regard only the *how* and not the *why* of the phenomena. Ignoring the *why* for the moment, let us seek the origin of the current which, by being conducted through the armature, has produced the striking effect we have just witnessed. This current reaches the car through an overhead or underground wire. All that is essential is that some conducting medium, such as an iron rail, or a copper wire, shall form an unbroken connection between the motor apparatus and the central dynamo where the power is generated—the return circuit being made either by another wire or by the ordinary rails.

The central dynamo in question will be found, if we visit the power-house, to be a ponderous affair, suggestive to the untechnical mind of impenetrable mysteries. Yet in reality it is a device essentially the same in construction as the motor which drives the train. That is to say, its unit of construction consists of a wire-wound armature revolving on an axis and fitted between the poles of an electromagnet. Here, however, the sequence of phenomena is reversed, for the armature, instead of receiving a current of electricity, is made to



Lower figure copyrighted by N. Y. Edison Co.

AN ELECTRIC TRAIN AND THE DYNAMO THAT PROPELS IT.

The lower figure gives an interior view of a power house of the Manhattan Elevated Railway Company. The upper figure shows one of the electric engines operating on the New York Central Lines just outside of New York. The power is conveyed to the engine by a third rail clearly shown in the picture.

revolve by a belt adjusted to its axis and driven by a steam engine. The wire coils of the armature thus made to revolve cut across the so-called lines of magnetic force which connect the two poles of the magnet, and in so doing generate a current of induced electricity, which flows away to reach in due course the third rail or the trolley-wire, and ultimately to propel the motor.

It is hardly necessary to state that in actual practice this generating dynamo is a complex structure. The armature is a complex series of coils of wire; the electromagnets surrounding the armature are several or many; and there is an elaborate system of so-called commutators through which the currents of electricity—which would otherwise oscillate as the revolving coil cuts the lines of magnetic force in opposite directions—are made to flow in one direction. But details aside, the foundation facts upon which everything depends are (1) that a coil of wire when forced to move so that it cuts across the lines of force in any magnetic field develops a so-called induced current of electricity; and (2) that such an induced current possesses power of magnetic attraction and repulsion. These facts were discovered more than sixty years ago, and carefully studied by Michael Faraday, Joseph Henry, and others. Faraday found that such an induced current could be produced not merely with the aid of an iron magnet, but even by causing a wire to cut the lines of force that everywhere connect the north and south poles of the earth,—the earth being indeed, as William Gilbert long ago demonstrated, veritably a gigantic magnet. Moreover, these relations are reciprocal; so that if a wire through which a current of electricity is passing is placed across a magnetic field, the wire is impelled to move in a plane at right angles to the direction of the lines of force. It is forcibly thrust aside. This side-thrust acting on coils of wire is what produces the revolution of the armature of the electric motor.

THE ORIGIN OF THE DYNAMO

The very first studies that had to do with the mutual relations of electricity and magnetism were made by Hans Christian Oersted, the Dane, as early as 1815. He discovered that a magnetic needle is influenced by the passage near it of a current of electricity, demonstrating, therefore, that the electric current in some way invades the medium surrounding any conductor along which it is passing. Oersted's experiments were repeated, and some new phenomena observed by the Frenchman André Marie Ampère and Dominique François Arago. Arago constructed an interesting device, in which a metal disk was made to revolve in the presence of a current of electricity; but neither he nor anyone else at the time was able to explain the phenomenon.

In 1824 an advance was made through the construction of the first electric magnet by Sturgeon. Hitherto it had not been known that a magnet could be made artificially, except by contact with a previously existing magnet. Sturgeon showed that any core of iron may be rendered magnetic if wound with a conducting wire, through which a current of electricity is passed. The experiments thus inaugurated were followed up in

America by Joseph Henry of Albany who made enormous electromagnets, capable of sustaining great weights. One of his magnets, operated by a single cell, was able to lift six hundred and fifty pounds of metal.

It was this apparatus which was subsequently to make possible the utilization of electricity as a working force, but as yet no one suspected its possibilities in this direction.

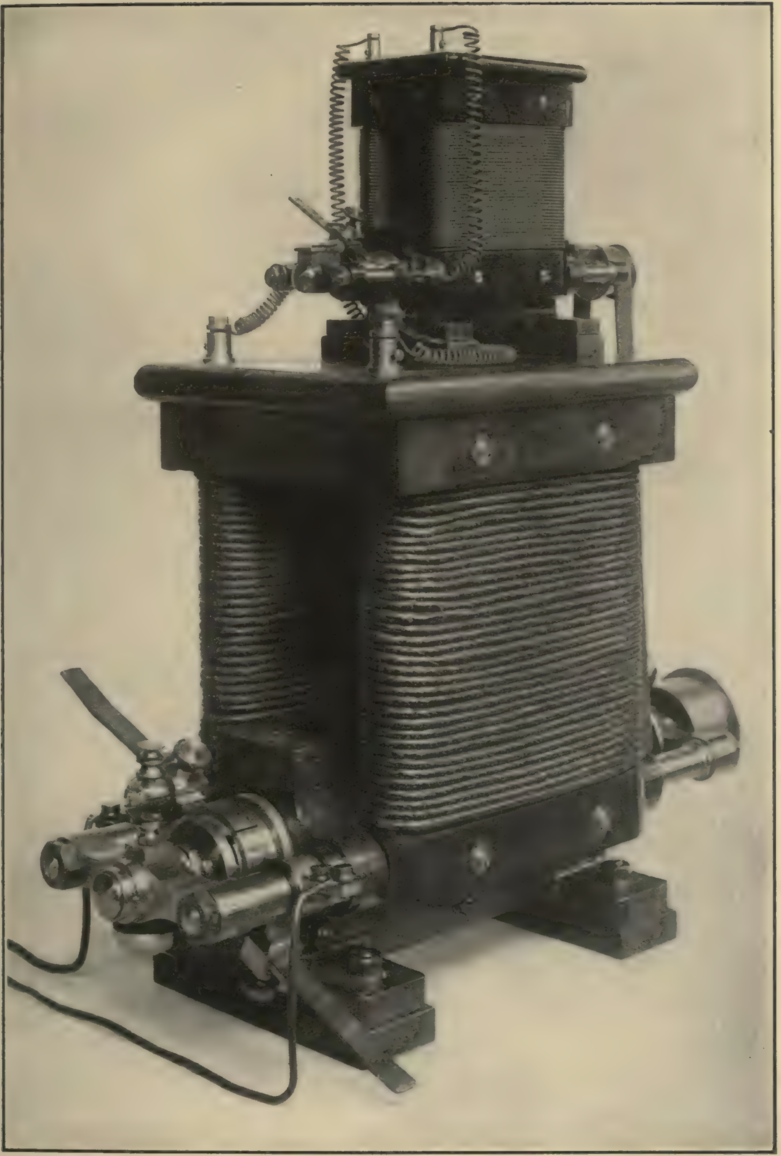
It remained for Michael Faraday, in 1831, to make the final experiment which laid the secure foundation for the new science of electrodynamics. Faraday constructed a tiny apparatus, consisting of a magnet between the poles of which a metal disk was placed in such a way that it could revolve on an axis, the disk being connected with a wire conveying an electric current.

The details as to this most ingenious mechanism need not be given here. Suffice it that Faraday demonstrated the interrelations of magnetism and electricity and the possibility of causing a metal disk to revolve through this mutual interaction. In so doing he constructed the first dynamo-electric machine. In his hands it was a mere laboratory toy, but the principles involved were fully elaborated by the original experimenter, and stated in precise language which modern investigators have not been able to improve upon.

Several decades elapsed after Faraday's initial experiment before the phenomena of magneto-electricity were proved to have any considerable commercial significance. A vast amount of ingenuity was required to devise a mechanism which could advantageously utilize the principle in question for commercial purposes. Indeed the early experimenters did not at once get upon the right track, as their efforts were influenced disadvantageously by an attempt to follow the principle of the steam engine. Some interesting mechanisms were devised whereby the motion of an armature in being drawn toward an electromagnet could be translated into rotary motion through the use of crank-shafts and even of beams, precisely comparable to those employed in the steam engine. Such devices worked with a comparatively low degree of efficiency and were totally abandoned so soon as the idea of getting rotary motion directly from the magnet or armature was made feasible. The names of Saxton, Clarke, Woolrich, Wheatstone, and Werner Siemens are intimately connected with the early efforts at utilization of magneto-electric power. The shuttle-wound armature of Siemens, invented in 1854, marked an important progressive step.

PERFECTING THE DYNAMO

The first separately excited dynamos were constructed by Dr. Henry Wilde, F.R.S., between 1863 and 1865, and this invention paved the way for rapid progress. In 1866–7 Varley, Siemens, Wheatstone, and Ladd constructed machines with several iron electromagnets, self-excited, which were described as dynamo-electric machines, a term afterward contracted to dynamos. In 1867 Dr. Wilde improved the armature by introducing several coils arranged around a cylinder; the current from a few of the coils was rectified and used



WILDE'S SEPARATELY EXCITED DYNAMO

Dr. Wilde invented and patented (1863–5) the first separately excited dynamo, with which he demonstrated that the feeble current from a small magneto-electric machine would, by the expenditure of mechanical power, produce currents of great strength from a large dynamo.

to excite the field magnet, while the main current as given off by the rest of the coils was taken off by ring-contacts, the machine being a self-exciting, alternating-current dynamo.

The Italian, Picnotti, in 1864 invented a ring armature which, although provided with teeth was wound with coils in such a way as to obtain a very uniform current; but the practical introduction of the continuous-current machines dates from 1870, when Gramme re-invented the ring and gave it the form which is still in vogue. Von Alteneck in 1873 converted the Siemens shuttle armature along the same lines and so introduced the drum arrangement which has since been very extensively adopted.

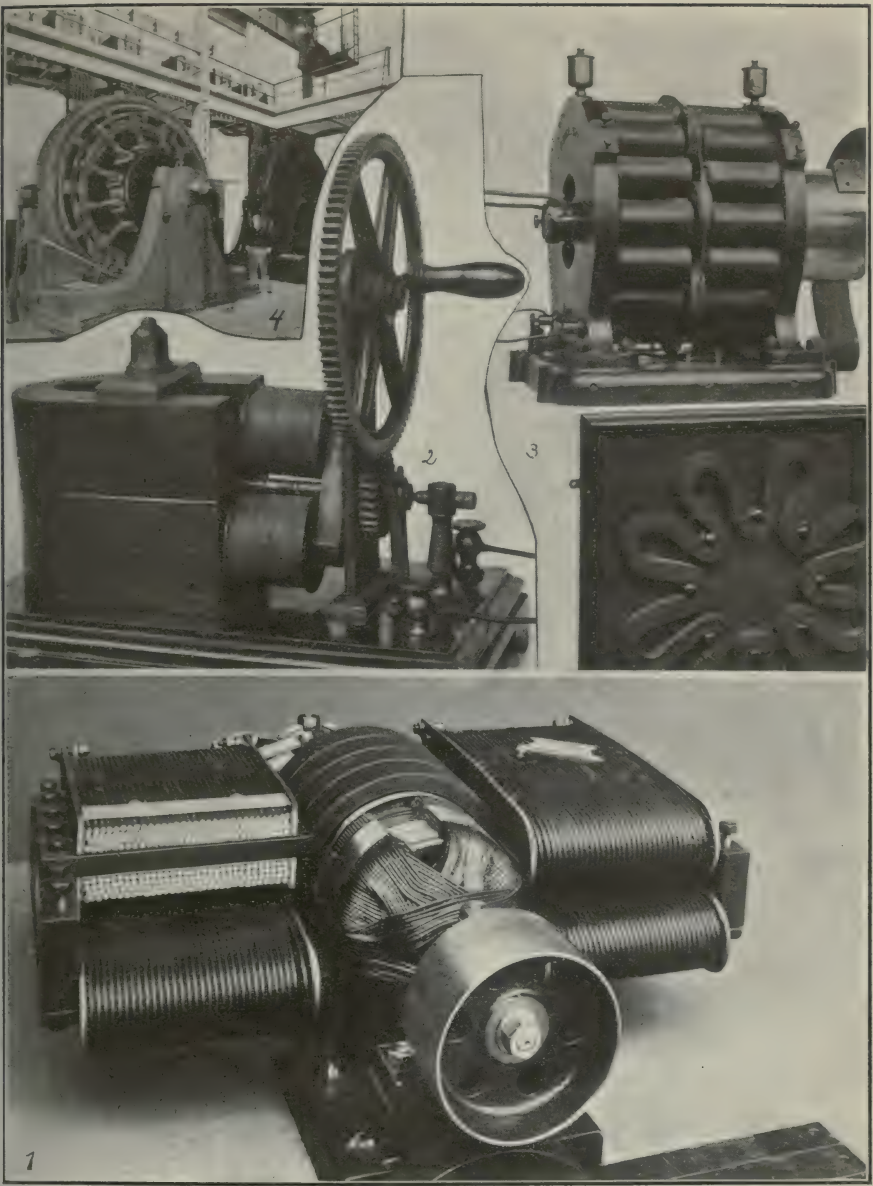
Thus through the efforts of a great number of workers the idea of utilizing electromagnetic energy for the purposes of the practical worker came to be a reality. Numberless machines have been made differing only as to details that need not detain us here. Everyone is familiar with sundry applications of the dynamo to the purposes of to-day's applied science. It must be understood, of course, that the amount of electricity generated in any dynamo is precisely measurable, and that by no possibility could the energy thus developed exceed the energy required to move the coils of wire. Were it otherwise the great law of the conservation of energy would be overthrown. In actual practice, of course, there is loss of energy in the transaction. The current of electricity that flows from the very best dynamo represents considerably less working power than is expended by the steam engine in forcibly revolving the armature.

In the early days of experiments the loss was so great as to be commercially prohibitive. With the perfected modern dynamo the loss is not greater than fifteen per cent; but even this, it will be noted, makes electricity a relatively expensive power as compared with steam,—except, indeed, where some natural power, like the Falls of Niagara, can be utilized to drive the armature.

A MYSTERIOUS MECHANISM

The efficiency of the modern dynamo is due largely to the fact that when the poles of the magnet are made to face each other, the lines of magnetic force passing between these poles are concentrated into a narrow compass. With the ordinary bar magnet, as everyone is aware, these lines of force circle out in every direction from the poles in an almost infinite number of loops, all converging at the poles, and becoming relatively separated at the equator in a manner which may be graphically illustrated by the lines of longitude drawn on an ordinary globe.

It is obvious that with a magnet of such construction only a small proportion of the lines of magnetic force could be utilized in generating electricity. But, as already mentioned, when the magnet is so curved that its poles face each other, the lines of force, instead of widely diverging, pass from pole to pole almost in a direct stream. The strength of this magnetic stream may be increased almost indefinitely by winding the iron core of the magnet with the coil of wire through which the electric current is passed, thus constituting the electro-



THE EVOLUTION OF THE DYNAMO.

Fig. 1.—A small example of the original commercial form of the drum armature machine, patented in 1873 by Dr. Werner Siemens and F. Von Hefner Alteneck. The armature is a development of the Siemens shuttle form of 1856, and gives a nearly continuous current. Fig. 2.—An early experimental dynamo. Fig. 3.—Ferranti's original dynamo, patented in 1882–1883. The field magnets are stationary and consist of two sets of electro-magnets each with 16 projecting pull pieces, between which the armature revolves. Fig. 4.—The gigantic rotary converters of the Manhattan Elevated Railway.

magnet which has replaced the old permanent magnet in all modern commercial dynamos.

An electromagnet may be sufficiently powerful to lift tons of iron. The force it exerts, therefore, is very tangible in its results. Yet it seems mysterious, because so many substances are unaffected by it. You may place your head, for example, between the poles of the most powerful magnet without experiencing any sensation or being in any obvious way affected. You may wave your hand across the lines of force as freely as you may wave it anywhere else in space. Apparently nothing is there. But were you to attempt to pass a dumb-bell or a bar of iron across the same space, the unseen magnetic force would wrench it from your grasp with a power so irresistible as to be awe-inspiring.

Similarly, the armature, when its coils of wire are adjusted between the poles of the magnet, is held in a vise-like grip by the invisible but potent lines of magnetic force which tend to make it revolve. It requires a tremendous expenditure of energy—supplied by the steam-engine or by water power—to enable the coiled wires of the generating armature to stem the current of magnetic force, which is virtually what is done when the armature revolves in such a way as to produce electrical energy. Part of the mechanical energy thus expended is transformed into heat and dissipated into space; but the main portion is carried off, as we have seen, through the coiled wires of the armature in the form of what we term the current of electricity, to be re-transformed in due course into the mechanical energy that moves the car.

It appears, then, that the phenomena of the electric dynamo depend upon the curious relations that exist between magnetism and electricity. Granted the essential facts of magneto-electric induction, all the phenomena of the dynamo are explicable. But how explain these facts themselves? Why is an electric current generated in a coil of wire moving in a magnetic field? And why is a wire carrying a current of electricity, when placed across a magnetic field, impelled to move at right angles to the lines of magnetic force? No thoughtful person can consider the subject without asking these questions. But as yet no definitive answer is forthcoming. Some suggestive half-explanations, based on an assumed condition of torsion or strain in the ether, have been attempted, but they can hardly be called more than scientific guesses.

Meanwhile, it may be understood that the mutual relations of the magnetic and electrical forces just referred to are not at all dependent upon the manner in which the electric current is generated. The magneto-electric motor may be operated as well with a chemical battery as with such a mechanical generating dynamo as has just been described. The storage-batteries which have been employed in some street railways and those which propel the electric cabs about our city streets furnish cases in point. The only reason these are not more generally employed is that the storage battery has not yet been perfected so that it can produce a large supply of electricity in proportion to its weight, and produce it economically.

X

NIAGARA IN HARNESS

"HARNESSING NIAGARA"—the phrase has been a commonplace for a generation; but until very recently indeed it was nothing more than a phrase. Almost since the time when the Falls were first viewed by a white man the idea of utilizing their powers has been dreamed of. But until our own day—until the last decade—science had not shown a way in which the great current could be economically shackled. A few puny mill-wheels have indeed revolved for thirty years or so, but these were of no greater significance than the thousands of others driven by mountain streams or by the currents of ordinary rivers. But about a decade ago the engineering skill of the world was placed in commission, and to-day Niagara is fairly in harness.

If you have ever seen Niagara—and who has not seen it?—you must have been struck with the metamorphosis that comes over the stream about half a mile above the falls. Above this point the river flows with a smooth sluggish current. Only fifteen feet have the waters sunk in their placid flowing since they left Lake Erie. But now in the course of half a mile they are pitched down more than two hundred feet. If you follow the stream toward this decline you shall see it undergo a marvelous change. Of a sudden the placid waters seem to feel the beckoning of a new impulse. Caught with the witchery of a new motion, they go swirling ahead with unwonted lilt and plunge, calling out with ribald voices that come to the ear in an inchoate chorus of strident, high-pitched murmurings. Each wavelet seems eager to hurry on to the full fruition of the cataract. It lashes with angry foam each chance obstruction, and gurgles its disapproval in ever-changing measures. Even to the most thoughtless observer the mighty current thus unchained attests the sublimity of almost irresistible power. Could a mighty mill-wheel be adjusted in that dizzy current, what labors might it not perform? Five million tons of water rush down this decline each hour, we are told; and the force that thus goes to waste is as if three million unbridled horses exhausted their strength in ceaseless plunging. This estimate may be only a guess, but it matters not whether it be high or low; all estimates are futile, all comparisons inadequate to convey even a vague conception of the majesty of power with which the mighty waters rush on to their final plunge into the abysm.

It is here, you might well suppose, where the appalling force of the current is made so tangible, that man would place the fetters of his harness, making the madcap current subject to his will. You will perhaps more than half expect to see gigantic mechanisms of man's construction built out over the rapids or across the face of the cataract—so much has been said of æstheticism versus commercialism in connection with the attempt to utilize Niagara's power. But whatever your fears in this regard, they will not be realized. Inspect the rapids and the falls as you may, you will see no evidence that man has tampered with their pristine freedom. Subtler means have been employed to tame the wild steed. The mad waves that go dashing down the rapids are as free and untrammeled to-day as they were when the wild Indian was the only witness of their tempestuous activity. Such portions of the current as reach the rapids have full license to pass on untrammeled, paying no toll to man. The water which is made to pay tribute is drawn from the stream up there above the rapids, where it lies placid and as yet unstirred by the beckoning incline. To see Niagara in harness, then, you must leave the cataract and the rapids and pass a full mile up the stream where the great river looks as calm as the Hudson or the Mississippi, and where, under ordinary conditions, not even the sound of the falls comes to your ear.

Prosaic enough it seems to observe here nothing more startling than a broad *cul de sac* of stagnant water, like the beginning of a broad canal, extending in for a few hundred yards only from the main stream; its waters silent, currentless, seemingly impotent. This stagnant pool, then, not the whirling current below, is to furnish the water whose reserve force of energy of position is drawn upon to serve man's greedy purpose. Coming from the rapids and cataract to this stagnant canal, you seem to step from the realm of poetic beauty to the sordid realities of the work-a-day world. Of a truth it would seem that "harnessing Niagara" is but a far-fetched metaphor.

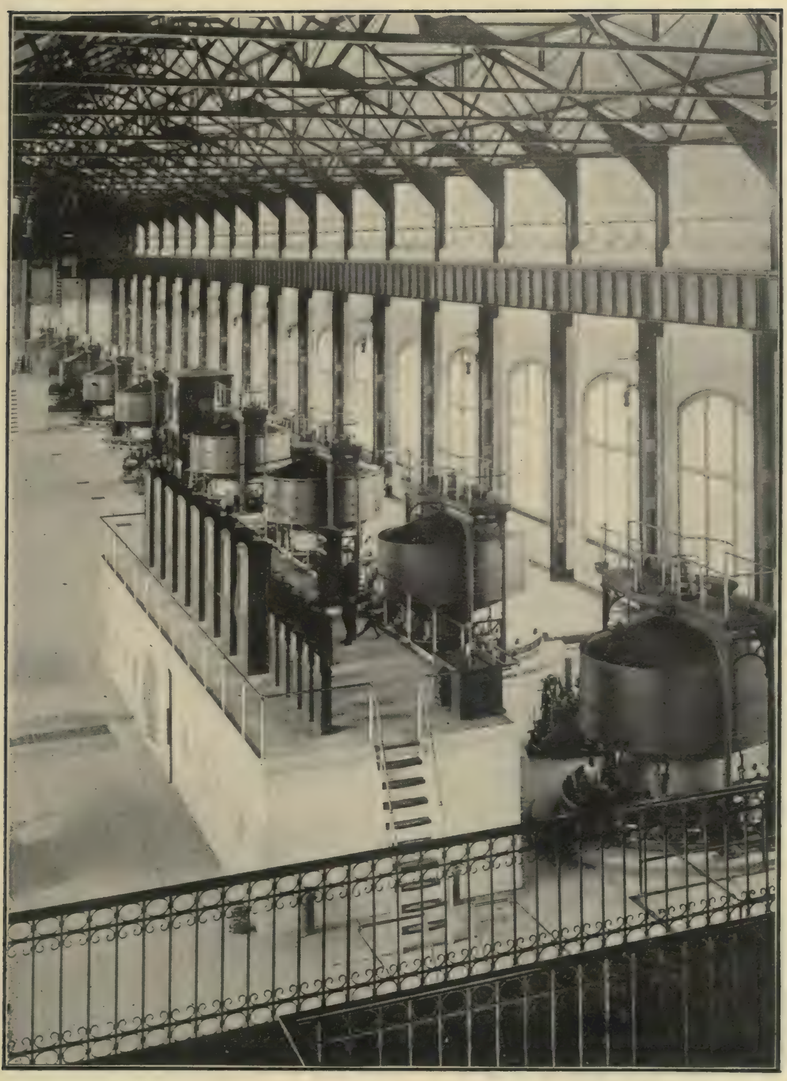
WITHIN THE POWER-HOUSE

And yet if you will turn aside from the canal and enter one of the long, low buildings that flank it on either side, you will soon be made to feel that the metaphor was amply justified. Little as there was exteriorly to suggest it, you are entering a fairyland of applied science, and within these plain walls you shall witness evidences of the ingenuity of man that should appeal scarcely less to your imagination than the sight of the cataract itself in all its sublimity of power.

For within these walls, by a miracle of modern science, the potential energy which resides in the water of the canal is transformed into an electrical current which is sent out over a network of wires to distant cities to perform a thousand necromantic tasks,—propelling a street car in one place, effecting chemical decompositions in another; turning the wheels of a factory here and lighting the streets of a city there; in short, subserving the practical needs of man in devious and wonderful ways.

Even as you gazed disdainfully at the stagnant canal, its waters, miraculously transformed, were propelling the trolley cars along the brink of the cliff over there on the Canadian shore, and at the same time were turning the wheels in many a factory in the distant city of Buffalo. After all, then, the quiet pool of water was not so prosaic as it seemed.

As you stand in the building where this wonderful transformation of power is effected, the noble simplicity of the vista heightens the mystery. The most significant



VIEW IN ONE OF THE POWER HOUSES AT NIAGARA.

Each of the top-like dynamos generates 5000 horse-power.

thing that strikes the eye is a row of great mushroom-like affairs, for all the world like giant tops, that stand spinning—and spinning. These great tops are about a dozen feet in diameter. They are whirling, so we are told, at a rate of two hundred and fifty revolutions per minute. Hour after hour they spin on, never varying in speed, never faltering; day and night are alike to them, and one day is like another. They are as ceaselessly active, as unwearying as Niagara itself, whose power they symbolize; and, like the great Falls, they murmur exultingly as they work.

The giant tops which thus seem to bid defiance to the laws of motion are in reality electric dynamos, no different in principle from the electric generators with which some visit to a street-car power-house has doubtless made you familiar. The anomalous feature of these dynamos—in addition to their size—is found in the fact that they revolve on a vertical shaft which extends down into a hole in the earth for more than a hundred feet, and at the other end of which is adjusted a gigantic turbine water-wheel. Water from the canal is supplied this great turbine wheel through a steel tube or penstock, seven feet in diameter. As the turbine revolves under stress of this mighty column of water, the long shaft revolves with it, thus turning the electric generator at the other end of the shaft—the generator at which we are looking, and which we have likened to a giant top—without the interposition of any form of gearing whatever.

To gain a vivid mental picture of the apparatus, we must take an elevator and descend to the lower regions where the turbine wheel is in operation. As we pass down and down, our eyes all the time fixed on the vertical revolving shaft, which is visible through a network of bars and gratings, it becomes increasingly obvious that to speak of this shaft as standing in "a hole in the ground" is to do the situation very scant justice. A much truer picture will be conceived if we think of the entire power-house as a monster building, about two hundred feet high, all but the top story being underground. What corresponds to the ground floor of the ordinary building is located one hundred and fifty feet below the earth's surface; and it is the top story which we entered from the street level, thus precisely reversing the ordinary conditions.

PENSTOCKS AND TURBINES

As we descend now and reach at last the lowest floor of the building, we step out into a long narrow room, the main surface of which is taken up with a series of gigantic turnip-shaped mechanisms, each one having a revolving shaft at its axis; while from its side projects outward and then upward a seven-foot steel tube, for all the world like the funnel of a steamship. This seeming funnel—technically termed a penstock—is in reality the great tube through which the massive column of water finds access to the turbine wheel, which of course is incased within the turnip-shaped mechanism at its base.

As you stand there beside this great steel mechanism a sense of wonderment and of utter helplessness takes possession of you. As you glance down the hall at this series of great water conduits, and strain your eyes upward in the endeavor to follow the great funnel to its very end, an oppressive sense of the irresistible weight of the great column of water it supports comes to you, and you can scarcely avoid a feeling of apprehension. Suppose one of the great tubes were to burst?—we should all be drowned like rats in a hole. There is small danger, to be sure, of such a contingency; but it is well worth while to have stood thus away down here at the heart of the great power-house to have gained an awed sense of what man can accomplish toward rivaling the wonders of nature. To have stood an hour ago on the ice bridge at the foot of the most tremendous cataract in the world, where Nature exhausts her powers amidst the mad rush and roar of seething waters; and now to stand beneath this other column of water which effects a no less wonderful transformation of energy, serenely, silently,—is to have run such a gamut of emotions as few other hours in all your life can have in store for you.

A MIRACULOUS TRANSFORMATION OF ENERGY

There are eleven of these great turbine mechanisms, each with a supplying funnel of water and a revolving shaft extending upward to its companion dynamo, in the room in which we stand. Energy representing fifty-five thousand horse-power is incessantly transformed and made available for man's use in the subterranean building in which we stand. And there is not a pound of coal, not a lick of flame, not an atom of steam involved in the transformation. There are no dustgrimed laborers; there is no glare of furnace, no glow of heat, no stifling odor of burning fuel;—there is only the restful hum of the machinery that responds to the ceaseless flow of the silent and invisible waters. Day and night the mighty river here pulls away at its turbine harness; and man, having once adjusted that harness, may take his ease and enjoy the fruits of his ingenuity.

As we return now to the top of the building, we shall view the spinning dynamos with renewed interest, and a few facts regarding their output of energy may well claim our attention. In their principle of action, as we have seen, all dynamos are alike,—depending upon the mutual relations between the wire-wound armature and a magnetic field. In the present case the magnets are made to revolve and the armatures are stationary, but this is a mere detail. There is one feature of these dynamos, however, which is of greater importance,—the fact namely that they operate without commutators, and therefore produce alternating currents. This fact has an important bearing upon the distribution of the current. Each of the dynamos before us generates the equivalent of five thousand horse-power of energy. There are eleven such dynamos here before us; there are ten more in the power-house on the other side of the canal, giving a total of one hundred and five thousand horse-power for this single plant; and there are five such plants now in existence or in course of construction to utilize the waters of Niagara, three being on the Canadian shore. When in full operation the aggregate output of these plants will be six or seven hundred thousand horse-power.

SUBTERRANEAN TAIL-RACES

As we step from the door of the power-house and stand again beside the canal whose waters produce the wonderful effects we have witnessed in imagination, one question remains to be answered: What becomes of the water after it has passed through the turbine wheels down there in the depths? The answer is simple: All the water from the various turbines flows away into a great subterranean canal which passes down beneath the city of Niagara Falls, and discharges finally at the level of the rapids a few hundred yards below the Falls. The construction of this subterranean canal would in itself have been considered a great engineering feat a few decades ago; but of late years mountain tunnels, such subterranean railways as the London "tube system" and tunnels beneath rivers have robbed such structures of their mystery. It may be added that another such subterranean canal, to serve as a tail-race for one of the new Canadian plants, extends beneath the cataract itself, discharging not far from the centre of the Horsehoe Falls. Another of the power companies utilizes the water of the old surface canal which extends to the brink of the gorge some distance below the Falls. Yet another company on the Canadian side conveys water from far above the rapids in a gigantic closed tube to the brink of the gorge just below the Canadian Falls, above the point where their power-house is located.

But the principle involved is everywhere the same. The idea is merely to utilize the weight of falling water.

The water of Niagara River is of course no different from any other body of water of equal size. It is merely that its unique position gives the engineer an easy opportunity to utilize the potential energy that resides in any body of water—or, for that matter, in any other physical substance—lying at a high level. In due course, doubtless, other bodies of water, such as mountain lakes and mountain streams will be similarly put into electrical harness. The electrical feature is of course the one that most appeals to the imagination. But it may be well to recall that the ultimate source of all the power in question is gravitation. People fond of philosophical gymnastics may reflect with interest that, according to the newest theory, gravitation itself is, in the last analysis, an electrical phenomenon—a reflection which, it will be noted, leads the mind through a very curious cycle.

THE EFFECT ON THE FALLS

Much solicitude has been expressed as to the possible effect, upon the Falls themselves, of this withdrawal of water. For the present, it is admitted, there is no visible effect; and to the casual observer it may seem that almost any quantity of water the power-houses are likely to need might be withdrawn without seriously marring the wonderful cataract. But the statistics supplied by the power companies, taken in connection with estimates as to the bulk of water that passes over the Falls, do not support this optimistic view. Taking what seems to be a reasonable estimate for a basis of computation it would appear that when the power-houses now rapidly approaching completion are in full operation, the total withdrawal of water from the stream will represent a very appreciable fraction of its entire bulk—one-twenty-fifth at the very least, perhaps as much as one-tenth. Such a diminution as this will by no means ruin the Falls, yet it would seem as if it must sensibly affect them, particularly at some places near Goat Island, where the water flows at present in a very shallow stream. Be that as it may, however, the power-houses are there, and it is probable that their number will be added to as years go on. Whether commercialism or æstheticism will win in the end, it remains for the legislators of the future to decide.

Meanwhile, it is gratifying to reflect that for the present the Falls retain their pristine beauty, even though part of the water that is their normal due is turned aside and made to do service for man in another way. There is only one reason why the Falls have escaped desecration so long as they have; that reason being the very practical one that until quite recently man has not known how to utilize their powers to advantage. The effort was indeed made, a full generation ago, through the construction of the canal leading from the upper river to the bluffs overlooking the gorge below the cataract. Here a few mill-wheels were set whirling, and a tiny fraction of the potential energy of the water was utilized. There was no mechanical difficulty involved in the utilization of this power. Mill-wheels are a familiar old-time device, and even the turbine wheel is modern only in a relative sense of the word. And it must be understood that the turbine water-wheel utilizes the greatest proportion of the power of falling water of any contrivance as yet known to mechanics. It was possible, then, to utilize the water of Niagara with full effectiveness fifty years ago, so far as the direct action of the water-wheel upon machinery near at hand was concerned. The sole difficulty lay in the fact that only a small amount of machinery can be placed in any one location. The real problem was not how to produce the power, but how to transmit it to a distance.

THE TRANSMISSION OF POWER

For fifty years mechanical engineers have looked enviously upon unshackled Niagara, and have striven to solve the problem of transmitting its power. It were easy enough to harness the great Fall, but futile to do so, so long as the power generated must be used in the immediate vicinity. So, many schemes for transmitting power were tried one after another, and as often laid aside. There was one objection to even the best of them—the cost. At one time it was thought that compressed air might solve the problem. But repeated experiments did not justify the hope. Then it was believed that the storage battery might be made available. The storage battery, it might be explained, does not really store electricity in the sense in which the Leyden jar, for example, stores it. Rather is it to be likened to an ordinary voltaic cell, the chemical ingredients of which have been rendered active by the passage of the electric current. The active ingredients of the storage battery are usually lead compounds, which through action of the electric currents have been decomposed and placed in a state of chemical instability. The dissociated molecule of the lead compound, when permitted to reunite with the atoms with which it was formerly associated, will give up electrical energy.

Such a storage battery might readily be charged with electricity generated at Niagara Falls. It might then be conveyed to any part of the world, and, its poles being connected, the charge of electricity would be made available. Such storage batteries are in common use in connection with electric automobiles, as we have seen. But the great difficulty is that they are enormously heavy in proportion to the amount of electricity that they can generate; therefore, their transportation is difficult and expensive. In practice it is cheaper to produce electricity through the operation of a steam engine in a distant city than to transmit the electricity with the aid of a storage battery from Niagara. So the storage battery served as little as compressed air to solve the engineer's problem.

When the electric dynamo became a commercial success for such purposes as the operation of trolley lines it seemed as if the Niagara problem was on the verge of solution. And so, in point of fact, it really was, though more time was required for it than at first seemed needed. The power generated by the dynamo could, indeed, be transmitted along a wire, but not without great loss. Sir William Siemens, in 1877, had pointed out in connection with this very subject of the wasted power of Niagara, that a thousand horsepower might be transmitted a distance of, say, thirty miles over a copper rod three inches in diameter. But a copper rod three inches in diameter is enormously expensive, and when Siemens further stated that sixty per cent of the power involved would be lost in transmission, it was obvious that the method was far too wasteful to be commercially practicable.

For a time the experimenters with the transmission of electricity along a wire were on the wrong track. They were experimenting with a continuous current which, as we have seen, is produced from an ordinary dynamo with the aid of a commutator. But hosts of experiments finally made it clear that this form of current, no matter how powerful it might be, is unable to traverse considerable distance without great loss, being frittered away in the form of heat.

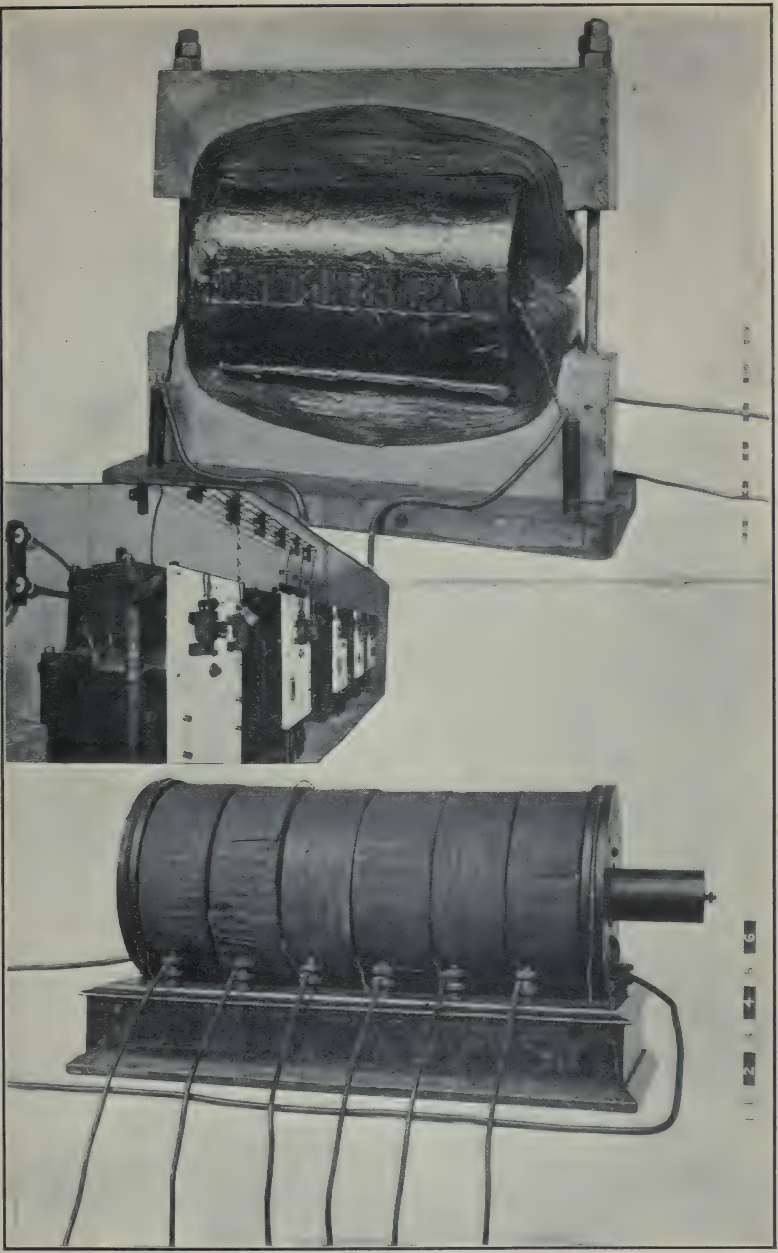
But the very term "continuous current" implies the existence of a current that is not continuous. In point of fact, we have already seen that a dynamo, if not supplied with a commutator, will produce what is called an alternating current, and such a current has long been known to possess properties peculiar to itself. It is, in effect, an interrupted current, and it is sometimes spoken of as if it really consisted of an alternation of currents which move first in one direction and then in another. Such a conception is not really justifiable. The more plausible explanation is that the alternating current is one in which the electrons are not evenly distributed and move with irregular motion. Perhaps we may think of the individual electrons of such a current as oscillating in their flight, and, as it were, boring their way into the resisting medium. In any event, experience shows that such a current, under proper conditions, may be able to traverse a conducting wire for a long distance with relatively small loss.

It must be understood, however, that the mere fact that a current alternates is not in itself sufficient to make feasible its transmission to a remote distance. To meet all the requirements a current must be of very high voltage. This means, in so far as we can represent the conditions of one form of energy in the terms of another, that it shall be under high pressure. Fortunately a relatively simple apparatus enables the electrician to transform a current from low to high voltage without difficulty. And so at last the problem of transmitting power to a distance of many miles has been solved. Electrical currents representing thousands of horse-power are to-day transmitted from Niagara Falls to the city of Buffalo over ordinary wires, with a loss that is relatively insignificant. A plant is in process of construction that will similarly transmit the power to Toronto; and it is predicted that in the near future the powers of Niagara will be drawn upon by the factories of cities even as far distant as New York and Chicago. Practical difficulties still stand in the way of such very distant transmission, to be sure, but these are matters of detail, and are almost certain to be overcome in the near future.

All this being explained, it will be understood that the sole reason why the new power-houses at Niagara generate electricity is that electricity is the one readily transportable carrier of energy. We have already explained that there is loss of energy when the steam engine operates the dynamo. At Niagara, of course, no steam is involved; it is the energy of falling water that is transformed into the energy of the electrical current. Moreover, the revolving dynamo is attached to the same shaft with the turbine water-wheel, so that there is no loss through the interposition of gearing. Yet even so, the electric current that flows from the dynamo represents somewhat less of energy than the water current that flows into the turbine. This loss, however, is compensated a thousandfold by the fact that the energy of the electric current may now be distributed in obedience to man's will.

"STEP UP" AND "STEP DOWN" TRANSFORMERS

The dynamos in operation at Niagara do not differ in principle from those in the street-car power-house, except in the fact that they are not supplied with commutators. We have seen that these dynamos are of enormous size. Those already in operation generate five thousand horse-power; others in process of construction will develop ten thousand. The generator which produces this enormous current is about eleven feet in diameter, and it makes two hundred and fifty revolutions per minute. The armatures are so wound that the result is an alternating current of electricity of twenty-two hundred volts. This current represents, it has been said, raw material which is to be variously transformed as it is supplied to different uses. To factories near at hand, indeed, the current of twenty-two hundred volts



ELECTRICAL TRANSFORMERS.

The upper figure shows Ferranti's experimental transformer built in 1888. It has a closed iron circuit, built up of thin strips filling the interior of the coil and having their ends bent over and overlapping outside. The lower figure shows a simple transformer known as Sturgeon's induction coil. The middle figure gives a view of the series of converters in the power house of the Manhattan Elevated Railway.

is supplied unchanged; but for more distant consumption it is raised to ten thousand volts; and that portion which is sent away to the factories of Buffalo and other equally distant places is raised to twenty-two thousand volts.

The transformation from a relatively low voltage to the high one is effected by means of what is called a step-up transformer. This is an apparatus which brings into play a principle of electric induction not very different from that which was responsible for the generation of the current of electricity in the dynamo. The principle is that evidenced in the familiar laboratory apparatus known as the Ruhmkorff coil. The transformer consists essentially of a primary coil of relatively large wire, surrounded by, but insulated from, a secondary coil of relatively fine wire. When the interrupted current is sent through the primary coil of such an apparatus, an induced counter-current is generated in the secondary coil. Of course there is no gain in the actual quantity of electricity, but the voltage of the current generated in the finer wire is greatly increased. For example, as we have seen, the current that came from the dynamo at twenty-two hundred volts is raised to ten thousand or twenty-two thousand volts. These proportions may be varied indefinitely by varying the relative sizes and lengths of the primary and secondary coils.

How shall we picture to ourselves the actual change in the current represented by this difference in voltage? We might prove, readily enough, that the difference is a real one, since a wire carrying a current of low voltage may be handled with impunity, while a similar wire carrying a current of high voltage may not safely be touched. But when we attempt to visualize the difference in the two currents we are all at sea. We may suppose, of course, that electrons spread out over a long stretch of the secondary coil must be more widely scattered. One can conceive that the electrons, thus relatively unimpeded, may acquire a momentum, and hence a penetrative power, which they retain after they are crowded together in a straight conductor. But this suggestion at best merely hazards a guess.

Arrived at the other end of its journey, the current which travels under this high voltage is retransformed into a low-voltage current by means of an apparatus which simply reverses the conditions of the step-up transformer, and which, therefore, is called a step-down transformer. The electricity which came to Buffalo as a twenty-two-thousand-volt current is thus reduced by any desired amount before it is applied to the practical purposes for which it is designed. It may, for example, be "stepped-down" to two thousand volts to supply the main wires of an electric-lighting plant; and then again "stepped-down" to two hundred volts to supply the electric lamps of an individual house.

Who that reads by the light of one of these electric lamps, let us say in Buffalo, and realizes that he is reading by the transformed energy of Niagara River, dare affirm that in our day there is nothing new under the sun?

XI

THE BANISHMENT OF NIGHT

ONE great fundamental advantage that man has won over the other animals is that although by nature a diurnal animal he has made night almost equally subject to his dominion through the use of artificial light. He thus establishes an average day of sixteen or eighteen hours in place of the twelve-hour day within which his activities would otherwise be restricted. Of course this conquest of the night began at an early stage of the human development, since a certain familiarity with the uses of fire was attained long before man came out of the ages of savagery. But when the transition had been made from the primitive torch to the simplest type of lamp, there was for many centuries a cessation of progress in this direction, and it remained for comparatively recent generations to provide more efficient methods of lighting. Indeed, the culminating achievements are matters which make the most recent history. It is the purpose of the ensuing pages to narrate the story of the successive practical achievements through which man has been enabled virtually to turn night into day.

PRIMITIVE TORCH AND OPEN LAMP

To moderns, in an age when even the time-honored gas jets and kerosene lamps are regarded as obsolescent, that ancient form of illuminant, the candle, seems about the most primitive form of light-producing apparatus. In point of fact, however, the candle holds no such place in the chronological order of lighting-device discovery, being a relatively late innovation. Indeed, lamps of various kinds, even those burning petroleum, were used thousands of years before the relatively clean and effective candle was invented.

The camp fires of primitive man must have suggested the use of a fire-brand for lighting purposes almost as soon as the discovery of fire itself; but the development of any means of lighting his caves or rude huts, even in the form of torches, was probably a slow process. For our earliest ancestors were not the nocturnal creatures their descendants became early in the history of civilization. To them the period of darkness was the time for sleeping, and their waking hours were those between dawn and dusk. It was only when man had reached a relatively high plane above the other members of the animal kingdom, therefore, that he would wish to prolong the daylight, and then the use of the torch made of some resinous wood would naturally suggest itself.

Just when the ancient lamp was invented in the form of a vessel filled with oil into which some kind of wick was dipped, cannot be ascertained, but its invention certainly antedated the Christian Era by several centuries. And it is equally certain that once this smoky, foul-smelling lamp had been discovered, it remained in use, practically without change or improvement, until the end of the twelfth century, the date of the invention of the candle. Such lamps were used by the Greeks and Romans, great quantities of them being still preserved. They were simply shallow, saucer-like vessels for holding the oil, into which the wick was laid, so arranged that the upper end rested against the edge of the vessel. Here the oil burned and smoked, capillarity supplying oil to the burning end of the wick, which was pulled up from time to time as it became shortened by burning, either with pincers made for the purpose, or perhaps more frequently by the ever useful hairpin of the matron.

As the thick wick did not allow the air to penetrate to burn the carbon of the oil completely, a nauseous smoke was given off constantly which was stifling when a draught of air prevented its escape through the hole in the roof—the only chimney used by the Greeks. And since this was the only kind of lamp known at the time, the palace of the Roman Emperor and hut of the Roman peasant were necessarily alike in their methods of lighting if in little else. The Emperor's lamps might be modeled of gold and set with precious stones, while those of the peasant were of rudely modeled clay; but each must have evoked, along with its dim light, an unwholesome modicum of smoke and malodor.

It was this form of lamp, practically unaltered except occasionally in design, that remained in common use during the Middle Ages; and when, at the close of the twelfth century, the "tallow candle" was invented, that now despised device must have been almost as revolutionary in its effect as the incandescent burner and the electric bulb were destined to be in a more recent generation. It burned with dazzling brilliancy in comparison with the oil lamp; it gave off no smoke and little smell; it needed no care, and it occupied little space. Then for the first time in the history of the world reasonably good house illumination became possible. Several additional centuries elapsed, however, before the idea was developed of placing a candle in a covered glass-sided receptacle, to form a lantern or a street lamp.

For generations the candle held supreme place, though its cost made it something of a luxury; doubly so if wax was substituted for tallow in its composition. But toward the close of the eighteenth century, when the action of combustion had begun to be better understood, attempts were made to improve the wicks and burners of oil lamps. In 1783, an inventor named Leger, of Paris, produced a burner using a broad, flat, ribbon-like wick in which practically every part of the oil supply was brought into contact with the air, producing, therefore, a steady flame relatively free from smoke. The flame, while broad, was extremely thin, and its light was consequently radiated very unevenly. Portions of a room lying in the direction of the long axis of the flame were but poorly lighted. To overcome this difficulty, a curved form of burner was adopted; and this led eventually to the invention of the circular Argand burner, the prototype of the best modern lamp-burners.

Stated in scientific terms, the problem of the ideal lamp-wick resolves itself into a question of how to supply oxygen to every portion of the flame in sufficient quantities to bring all the carbon particles to a temperature at which they are luminous. It occurred to Argand that this could be done by giving the wick a circular form like a cylindrical tube, giving the air free access to the centre of the tube as well as to its outer surface. In his lamp the reservoir of oil was placed at a little distance from, and slightly above, the tube holding the burner, connected with it by a small tube much as the tank of the modern "student lamp" connects with the burner. In this manner a fairly good lamp was produced,—a decided improvement over any made heretofore,—and when, in 1765, Quinquet added a glass chimney to this lamp a new epoch of artificial lighting was inaugurated. "This date is of as much importance in artificial lighting as is 1789 in politics," says one writer. "Between the ancient lamps and the lamps of Quinquet there is as much difference as between the chimney-place of our parlors and the fireplaces of our original Aryan ancestors, formed by a hole dug in the ground in the centre of their cabins."

A little later Carcel still further improved the Quinquet lamp by adapting a clock movement that forced the oil to rise to the wick, so that it was no longer necessary to have the burner and the reservoir separated by a tube. This was still further improved upon by substituting a spring for the clockwork, the result being a lamp of great simplicity, yet one which gave such results that it replaced the candle as a unit for measuring the illuminating power of different sources of light.

These various burners should not be confused with the modern burners of the ordinary kerosene lamps. Mineral oils had not as yet come into use for illuminating purposes, except as torches or in simple lamps like those of the Romans, as refining processes had not been perfected, and the smoke and odors from crude petroleum were absolutely intolerable in closed rooms.

Many other substances were tried in place of the heavy oils, such as the volatile hydrocarbons and alcohols, but with no great success. Early in the nineteenth century a lamp burning turpentine, under the name of "camphine," was invented that gave a good light and was smokeless; but like most others of its type, it was dangerous owing to its liability to explode. And it was not until methods of refining petroleum had been improved that "mineral-oil lamps"—the predecessors of the modern type of lamps—came into use.

The invention of this type of lamp was a relatively easy task—a simple transition and adaptation as processes of refining the oil were perfected. The principle of combustion was, of course, the same as in the Argand type of lamps burning animal and vegetable oils; but mineral oils are of such consistency that capillarity causes an abundant supply of oil to rise in the wick, so that clockwork and spring devices, such as were used in the Carcel lamps, could be dispensed with.

GAS LIGHTING

While the rivalry between the candle and the new forms of lamps was at its height, and just as the lamp was gaining complete supremacy, a new method of artificial illumination was discovered that was destined to eclipse all others for half a century, and then finally to succumb to a still better form. As early as the beginning of the eighteenth century the Rev. Joseph Clayton, in England, had made experiments in the distillation of coal, producing a gas that was inflammable. A little later Dr. Stephen Hales published his work on *Vegetable Staticks*, in which he described the process of distilling coal in which a definite amount of gas could be obtained from a given quantity of coal.

No practical use was made of this discovery, however, until over half a century later. But just at the close of the century a Scot, William Murdoch, became interested in the possibilities of gases as illuminants, and finally demonstrated that coal gas could be put to practical use. In 1798, being employed in the workshops of Boulton and Watt in Birmingham, he fitted up an apparatus in which he manufactured gas, lighting the workshops by means of jets connected by tubes with this primitive plant. Shortly after this, a Frenchman, M. Lebon, lighted his house in Paris with gas distilled from wood, and the Parisians soon became interested in the new illuminant. England seems to have been the first country to use it extensively in public buildings, however, the London Lyceum Theatre being lighted with gas in 1803. By 1810 the great Gas-Light and Coke Company was formed, and within the next five years gas street-lamps had become familiar objects in the streets of London, and house illumination by this means a common thing among the wealthier classes.

In the early days of gas-lighting the results were frequently disappointing, because no suitable and efficient type of burner had been devised; but in 1820 Neilson of Glasgow discovered the principle of the now familiar flat burner, of which more examples still remain in use the world over than of all other kinds combined. Indeed, this simple, but as we now regard it, inefficient burner, would probably have remained the best-known type for many years longer than it did had not the possibilities of lighting by electricity aroused persons interested in the great gas-plants to the fact that the new illuminant was jeopardizing their enormous investments; making it clear that they must bestir themselves and improve their flat burners if they would arrest disaster. To be sure, several modifications of the round Argand burner had been introduced from time to time, some of them being a distinct improvement over the flat burner, but these did not by any means seriously compete with electric light. And it was not until the incandescent mantle was perfected that gas as a brilliant illuminant was able to make a stand against its new competitor.

THE INCANDESCENT GAS MANTLE

It has been known almost since the beginnings of civilization that all solids can be made to emit light when heated to certain temperatures. Some substances were known to be peculiarly adapted to this purpose, such as lumps of lime, and for many years the calcium light or "lime-light" as it is popularly called, had been in use for special purposes, and was the most intense light known. This light is made by heating a block of lime to the highest practicable temperature by means of a blast of oxygen and coal gas; but such lights were too complicated and expensive for general purposes. It had been determined even as early as the beginning of the nineteenth century, however, that the high temperature necessary for producing this light was due in part at least to the fact that such a large amount of material had to be raised to incandescence. It was evident, therefore, that if a small amount of some such substance as lime and magnesia could be spread out so as to present a large surface in a small space, such as is represented by basket-work, sufficient heat for making it incandescent might be obtained from an ordinary gas-and-air blowpipe.

Here then was the germ of the "mantle" idea; and such an apparatus, known as the Clamond mantle, which was made of threads of calcined magnesia, was shown at the Crystal Palace Exhibition, in London, in 1882. Curiously enough, this mantle and burner worked in an inverted position, the mantle being suspended bottom upwards below the burner through which the blast of gas was forced. The light given by this mantle was most brilliant—little short of the older calcium light, in fact—but the device itself was too complicated to be of service for ordinary lighting purposes. The principle was correct, but the construction of the mantle was defective.

Meanwhile a German scientist, Dr. Auer von Welsbach, who had become famous in the scientific world for his researches on rare metals, was experimenting with certain oxides of different metals, and developing a method of handling them that finally resulted in the perfected incandescent burner in use at present. His process, which in theory at least was not entirely original with him, was to dip an open fabric of cotton into a solution of the nitrates of the metals to be used, drying it, and converting the nitrates into oxides by burning; the cotton fabric disappearing but leaving the skeleton of the oxide, which retained its original shape.

At the same time corresponding improvements were made in the type of burner, which is quite as essential to success as the mantle itself. It had been found that it was absolutely essential for such a burner to give a practically non-luminous flame, as otherwise the deposit of carbon particles will ruin the mantle. Two ways of obtaining this are possible; one by mixing a certain quantity of air with the gas before combustion, the other to burn the gas in so thin a flame that the air permeates it freely. Several burners of both types were used at first, but gradually the burners in which the air is mixed with the gas became the more popular, and most of the incandescent burners now on the market are of this type.

In the construction of mantles at the present time, while the principle of their use remains the same as that of the lime-light, lime itself is not used, the oxides of certain other metals having proved better adapted for the purpose. Thus the Welsbach patent of 1886 covered the use of thoria, either alone or mixed with other substances such as zirconia, alumina, magnesia, etc.; thoria being considered as having a very high power of light emission. Later it was discovered that pure thoria emits very little light by itself, although it possesses a refractory nature that gives a stability to the mantle unequalled by any other material as yet discovered. When combined with a small trace of the oxides of certain rare metals, however, such as uranium, terbium, or cerium, thoria mantles have a very high power of light emission, most modern mantles being composed of about ninety-nine per cent. thoria with one per cent. cerium.

In the ordinary method of manufacturing such mantles, a cotton-net cylinder about eight inches long, more or less according to the size of mantle required, is made, one end being contracted by an asbestos thread. A loop of the same material, or in some cases a platinum wire, is fastened across the opening, to be used for suspending the mantle when in use. The cotton-thread cylinder is soaked in a solution of the nitrates of the metals thorium and cerium, and is then wrung out to remove the excess, stretched on a conical mold, and dried. The flame of an atmospheric burner being applied to the upper part at the constricted position, the burning extends downward, converting the nitrates into oxides, and removing the organic matter. Considerable skill is required in this part of the process, as the regular shape of the mantle is largely dependent upon the regularity of the burning. As a finishing process a flame is applied to the inside of the mantle after it has cooled, to remove all traces of carbon that may remain.

The mantle is now ready for use, but is so fragile that it can scarcely be touched without breaking, and such handling as would be necessary for shipment would be out of the question. It is therefore strengthened temporarily by being dipped into a mixture of collodion and castor oil, which, when dry, forms a firm but elastic jacket surrounding all parts. It is this collodion jacket that is burned away when the new mantle is placed on the burner before the gas is turned on.

Quite recently the method of manufacturing mantles used by Clamond has been revived. In this method the cotton thread is dispensed with, the thread used being made from a paste containing the mantle material itself. The paste is placed in a proper receptacle the bottom of which is perforated with minute openings, and subjected to pressure, squeezing out the material in long filaments. When dry these are wound on bobbins, and, after being treated by certain chemical processes, are ready for weaving into mantles. It is claimed for mantles made on this principle that they last much longer and retain their light-emitting power more uniformly than mantles made by the older process.

THE INTRODUCTION OF ACETYLENE GAS

When the incandescent mantle had been perfected so as to be an economical as well an as efficient light-giver, the position of coal gas as an illuminant seemed again secured against the encroachments of its rivals, the arc and incandescent electric lights. But just at this time another rival appeared in the field that not only menaced the mantle lamp but the arc and incandescent light as well. Curiously enough, this new rival, acetylene gas, had been brought into existence commercially by the electric arc itself. For although it had been known as a possible illuminant for many years, the calcium carbide for producing it could not be manufactured economically until the advent of the electric furnace, itself the outcome of Davy's arc light.

Even as early as 1836 an English chemist had made the discovery that one of the by-products of the manufacture of metallic potassium would decompose water and evolve a gas containing acetylene; and this was later observed independently from time to time by several chemists in different countries. No importance was attached to these discoveries, however, and nothing was done with acetylene as an illuminant until the last decade of the nineteenth century. By this time electric furnaces had come into general use, and it was while working with one of these furnaces in 1892 that Mr. Thomas F. Wilson, in preparing metallic calcium from a mixture of lime and coal, produced a peculiar mass of dark-colored material, calcium carbide, which, when thrown into water, evolved a gas with an extremely disagreeable odor. When lighted, this gas burned with astonishing brilliancy, and, as its cost of production was extremely small, the idea of utilizing it for illuminating was at once conceived and put into practice.

The secret of the cheap manufacture of the carbide lies in the fact that the extremely high temperature required—about 4500° Fahrenheit—can be obtained economically in the electric furnace, but not otherwise. Thus electricity created its own greatest rival as an illuminant. It followed naturally that the ideal place for manufacturing the carbide would be at the source of the cheapest supply of electricity, and as the "harnessed" Niagara Falls represented the cheapest source of electric supply, this place soon became the centre of the carbide industry. Here the process of manufacture is carried out on an enormous scale. In practice, lime and ground coke are thoroughly mixed in the proportion of about fifty-six parts of lime to thirty-six parts of coke. When this mixture has been subjected to the heat of the electric furnace for a short time an ingot of pure calcium carbide is formed, surrounded by a crust of less pure material. The ingot and crust together represent sixty-four parts of the original ninety-two parts of lime and coke, the remaining twenty-eight parts being liberated as carbon-monoxide gas.

Calcium carbide as produced by this process is a dark-brown crystalline substance which may be heated to redness without danger or change. It will not burn except when heated in oxygen, and will keep indefinitely if sealed from the air. Chemically it consists of one atom of lime combined with two atoms of carbon (CaC_2); and to produce acetylene gas, which is a combination of carbon and hydrogen (C_2H_2) it is only necessary to bring it into contact with water, acetylene gas and slaked lime being formed. One pound of pure carbide will produce five and one half cubic feet of gas of greater illuminating power than any other known gas. The flame is absolutely white and of blinding brilliancy, giving a spectrum closely approximating that of sunlight. The light is so strongly actinic that it is excellent for photography.

Here was a gas that could be made in any desired quantities simply by adding water to a substance costing only about three cents a pound; its cost of production, therefore, representing only about one sixth of the dollar-per-thousand-feet rate usually charged for illuminating gas in our cities. It could be used in lamps and lanterns made with special burners and with the simple mechanism of a small water tank which allowed water to drip into a receptacle holding the carbide; or —reversing the process—an apparatus that dropped pieces of carbide into the water tanks. It was, in short, the cheapest illuminant known, generated by an apparatus that was simplicity itself.

There were, however, two defects in this gas: its odor was intolerable—the "smell of decayed garlic," it has been aptly called—and when mixed with air it was highly explosive. The first of these defects could be overcome easily; when the burner consumed all the gas there was no odor. The second, the explosive quality, presented greater difficulties. These were emphasized and magnified by the number of defective lamps that soon flooded the market, many of these being so badly constructed that explosions were inevitable. As a result a strong prejudice quickly arose against the gas, some countries passing laws prohibiting its use.

But further inquiry into the cause of the frequent disasters revealed the fact that when the burner of a lamp was constructed so that the air for combustion was supplied after the gas issued from the jet, there was no danger of explosion. And as lamps carefully constructed on this principle replaced the early ones of faulty construction, confidence in acetylene was restored. Methods were devised for supplying the gas for house-illumination like ordinary gas, and the occupants of country houses were afforded a means of lighting their houses on a scale of brilliancy hitherto unapproached, yet with economy and relative safety.

It was found also that the brilliancy of the acetylene flame was of such intensity that it could be used, like the electric arc light, as a search-light. It thus furnished a simple means of supplying small boats and vehicles with such lights, which they could not otherwise have had. It also supplied army signal-corps with an apparatus for flashing messages—an apparatus that was ideal on account of its simplicity and small size.

At the Pan-American Exhibition at Buffalo the various illuminating exhibits were among the most conspicuous and attractive features. But even amid the dazzling electrical displays the Acetylene Building was a noteworthy object. "It was the most brilliantly and beautifully lighted building in the grounds," declared one observer. "It sparkled like a diamond, and was the admiration of all visitors. In it were generators of all types—most of them supplying the gas for their own exhibits—several being the latest exponents of the art, so simple that they can be safely managed by unskilled labor; in fact, 'the brains are in the machines,' and when the attendant has charged them with carbide and filled them with water—given them food and drink—they will work steadily until they need another meal." Indeed, these exhibits at the Pan-American Exhibition demonstrated conclusively that acetylene gas occupies a field by itself as a practical illuminant.

At the same exposition a standard was established for good stationary acetylene generators for house-lighting, and the fact that a large number of generators fulfilled the requirements of the set of rules laid down showed how thoroughly the problem of handling this gas has been solved. Some of these rules used as tests are instructive to anyone interested in the subject, and a few of them are given here. They specified, for example, that—

"The carbide should be dropped into the water," the reverse process of letting the water drip on the carbide, as was done in most of the early generators, being condemned. "There must be no possibility of mixing air with the acetylene gas. Construction must be such that an addition to the charge of carbide can be made at any time without affecting the lights. Generators must be entirely automatic in their action—that is to say: after a generator has been charged, it must need no further attention until the carbide has been entirely exhausted. The various operations of discharging the refuse, filling with fresh water, charging with carbide, and starting the generator must be so simple that the generator can be tended by an unskilled workman without danger of accident. When the lights are out, the generation of gas should cease. The carbide should be fed automatically into the water in proportion to the gas consumed."

Perhaps the most significant thing, showing the stage of progress that has been made in overcoming the danger of explosions from acetylene gas, is that the use of generators meeting some such requirements as the above is not prohibited by fire underwriters. This in itself is very convincing evidence of their safety.

THE TRIUMPH OF ELECTRICITY

Throughout the ages primitive man had had constantly before him two sources of light other than that of the sun, moon, and stars. One of these, the fire of ordinary combustion, he could understand and utilize; the other, more powerful and more terrible, which flashed across the heavens at times, he could not even vaguely understand, and, naturally, did not attempt to utilize. But early in the seventeenth century some scientific discoveries were made which, although their destination was not even imagined at the time, pointed the way that eventually led to man's imitating in the most striking manner Nature's electrical illumination.

About this time Otto von Guericke, the burgomaster-philosopher of Magdeburg, in the course of his numerous experiments, had discovered some of the properties of electricity, by rubbing a sulphur ball, and among other things had noticed that when the ball was rubbed in a darkened room, a faint glow of light was produced. He was aware, also, that in some way this was connected with the generation of electricity, but in what manner he had no conception. In the opening years of the following century Francis Hauksbee obtained somewhat similar results with glass globes and tubes, and made several important discoveries as to the properties of electricity that stimulated an interest in the subject among the philosophers of the time. Gray in England, and Dufay in France, who became enthusiastic workers in the field, soon established important facts regarding conduction and insulation, and by the middle of the eighteenth century the production of an electric spark had become a commonplace demonstration.

But until this time it had not been demonstrated that this electric spark was actual fire, although there was no disputing the fact that it produced light. In 1744, however, this point was settled definitely by the German, Christian Friedrich Ludolff, who projected a spark from a rubbed glass rod upon the surface of a bowl of ether, causing the liquid to burst into flame. A few years later Benjamin Franklin demonstrated with his kite and key that lightning is a manifestation of electricity.

But neither the galvanic cell nor the dynamo had been invented at that time, and there was no possibility of producing anything like a sustained artificial light with the static electrical machines then in use. It was not until the classic discovery of Galvani and the resulting invention of the voltaic, or galvanic, cell shortly after, that the electric light, in the sense of a sustained light, became possible. And even then, as we shall see in a moment, such a light was too expensive to be of any use commercially.

DAVY AND THE FIRST ELECTRIC LIGHT

As soon as Volta's great invention was made known a new wave of enthusiasm in the field of electricity swept over the world, for the constant and relatively tractable current of the galvanic battery suggested possibilities not conceivable with the older friction machines. Batteries containing large numbers of cells were devised; one having two thousand such elements being constructed for Sir Humphry Davy at the Royal Institution, of London. By bringing two points of carbon, representing the two poles of the battery, close together, Davy caused a jet of flame to play between them—not a momentary spark, but a continuous light—a true voltaic arc, like that seen in the modern street-light to-day.

"When pieces of charcoal about an inch long and one-sixth of an inch in diameter were brought near each other (within the thirtieth or fortieth of an inch)," wrote Davy in describing this experiment, "a bright spark was produced, and more than half the volume of charcoal became ignited to whiteness; and, by withdrawing the points from each other, a constant discharge took place through the heated air, in a space equal to at least four inches, producing a most brilliant ascending arch of light, broad and conical in form in the middle. When any substance was introduced into this arch, it instantly became ignited; platina melted in it as readily as wax in a common candle; quartz, the sapphire, magnesia, lime, all entered into fusion; fragments of diamond and points of charcoal and plumbago seemed to evaporate in it, even when the connection was made in the receiver of an air-pump; but there was no evidence of their having previously undergone fusion. When the communication between the points positively and negatively electrified was made in the air rarefied in the receiver of the air-pump, the distance at which the discharge took place increased as the exhaustion was made; and when the atmosphere in the vessel supported only one-fourth of an inch of mercury in the barometrical gauge, the sparks passed through a space of nearly half an inch; and, by withdrawing the points from each other, the discharge was made through six or seven inches, producing a most brilliant coruscation of purple light; the charcoal became intensely ignited, and some platina wire attached to it fused with brilliant scintillations and fell in large globules upon the plate of the pump. All the phenomena of chemical decomposition were produced with intense rapidity by this combination."

It will be seen from this that as far as the actual lighting-part of Davy's apparatus was concerned, it was completely successful. But the source of the current —the most essential part of the apparatus—was such that even the wealthy could hardly afford to indulge in it as a luxury. The initial cost of two thousand cells was only a small item of expense compared with the cost of maintaining them in working order, and paying skilled operators to care for them. So that for the moment no practical results came from this demonstration, conclusive though it was, and the introduction of a commercial electric light was of necessity deferred until a cheaper method of generating electricity should be discovered.

This discovery was not made for another generation, but then, as seems entirely fitting, it was made by Davy's successor and former assistant at the Royal Institution, Sir Michael Faraday. His discovery of electromagnetic induction in 1831 for the first time made possible the electric dynamo, although still another generation passed before this invention took practical form. In the meantime, however, the magneto-electric machine of Nollet was used for generating an electric current for illuminating purposes as early as 1863; and when finally the dynamo-electric machine was produced by Gramme in 1870, engineers and inventors had at their disposal everything necessary for producing a practical electric illuminant.

It must not be supposed, however, that inventors stood by patiently with folded hands waiting for the coming of a machine that would furnish them with an adequate current without attempting to produce electric lamps. On the contrary, they were constantly wrestling with the problem, in some instances being fairly successful, even before the invention of the magneto-electric machine. Great advances had been made in batteries and cell construction over the primitive cells of the time of Davy, and for exhibition purposes, and even for lighting factories and large buildings, fairly good electric lights had been used before 1863.

The first practical application of electric lighting seems to have been made in France in 1849. During the production of the opera "The Prophet" the sun was to appear, and for this purpose an electric arc light was used. The success of this effort—an artificial sun being produced that seemed almost as dazzling to the astonished audience as Old Sol himself—stimulated further efforts in the same direction. The previous year W. E. Staite in England made experiments along similar lines in the large hall of the hotel of Sunderland. He generated a light "resembling the sun, or the light of day, and making candles appear as obscure as they do by daylight," according to the *Times* of the following morning. The electric light was therefore proved to be a practical illuminator, although it was not until the introduction of the Gramme dynamo-electric machine that its great economic utility was demonstrated.

THE JABLOCHKOFF CANDLE

In Sir Humphry Davy's experiments with his arc light he was led to believe that the light between the two points of carbon would be produced even in an absolute vacuum, if it were possible to create one. Several scientists at the time disputed this contention, and M. Masson, Professor of Physics in the *École Centrale des Arts et Manufactures* in Paris was particularly active in combatting the idea, maintaining that the arc had the same cause as the electric spark—the transport by electricity of the incandescent particles of the electrodes through the atmosphere. It was certain, at any rate, that no light was produced when the opposing carbons were brought into contact with each other, or were, on the other hand, separated too widely; and since there was a constant wearing away and shortening of the points, and thus a constantly increasing space between them, the great difficulty in making a practical lamp lay in regulating this distance automatically. It was finally accomplished, however, by the invention of a Russian officer, M. Jablochkoff, in 1876. The "Jablochkoff candle," as his lamp was called, marked an epoch in the history of electric lighting. One great merit of this invention was its simplicity, and while it has long since gone out of use, having been superseded by still simpler and better devices, it must always be recalled as an important stepping-stone in the progress of artificial illumination.

The name "candle" for Jablochkoff's lamp was suggested by the fact that the two carbons were placed side by side, instead of point to point, the light at the top thus suggesting a candle. Between these two carbons, and extending their whole length except at the very tips, was an insulating material that the arc could not pierce, but which burned away at a rate commensurate with the shortening of the carbons. In this manner the points were kept constantly at the proper distance without regulating-machinery of any kind. This ingenious apparatus had the additional advantage that it could be placed on any kind of a bracket or chandelier that was properly wired, thus dispensing with the cumbersome frames and machines of the point-to-point carbon arc lights then being introduced.

One difficulty at first encountered in using the Jablochkoff candle was the starting of the voltaic arc. In doing this it was necessary that contact be made between two carbon points, whether they lie parallel or point to point, and the necessary slight separation for producing the light effected later. To accomplish this Jablochkoff joined the tips of the carbons of his candle with a thin strip of carbon, which quickly burned away when the current was turned on, leaving the necessary space between the points for the arc.

There was one difficulty with the "candle" that seemed insurmountable for a time—the wasting of the two carbons was unequal, as in any arc light, the points thus gradually drawing apart until the passage of the current was no longer possible. To overcome this the rapidly wasting positive carbon was made double the thickness of its mate; but while this answered fairly well the thinner negative carbon gradually became heated by the increased resistance, and burned up too rapidly. The difficulty was finally overcome by the simple expedient of alternating the flow of the current, so that each carbon was alternately a positive and a negative pole. As the magneto-electric machines then in use produced alternating currents it was only necessary to use such machines for generating the current to produce an equal destruction of both carbons.

The simplicity and excellence of the light of these "candles" brought them at once into general popularity, not only in the large cities of Europe, but in many out-of-the-way places. Greece, Portugal, and other obscure European countries adopted them, and even Brazil, La Plata, and Mexico installed many plants. But stranger still, they were soon used for illuminating the palaces of the Shah of Persia and the King of Cambodia, and a little later were introduced into the residence of the savage King of Burma. In short, their use became universal almost immediately.

THE IMPROVED ARC LIGHT

About the time that Jablochkoff's candles were making such a sensation in Europe, Charles F. Brush, of Cleveland, Ohio, invented an arc light in which the carbons were set point to point, the distance being maintained and the necessary feed produced automatically in much the same manner as in the lamps used at present. Other inventions soon followed, some of the lamps being regulated by clockwork, some by electricity and magnetism.

The advantage of this type of arc lamp over the candle type—an advantage that led to its general adoption—was largely that of efficiency, a far greater amount of light being obtainable from the same expenditure of power by the point-to-point type of lamp.

In this lamp it is necessary that the points of carbon shall come in contact when the current is off, but be drawn apart a moment after the current is turned on, and remain at this fixed distance. To accomplish this, the lower carbon is usually made stationary, the feeding being regulated by the position of the upper carbon. In the usual type of modern lamp the passage of the current causes the points to separate the required distance through the action of an electromagnet the coils of which are traversed by the current. A clutch holds the carbon in place, the position of this being also determined by an electromagnet. The action is regulated by the difference in the resistance to the passage of the current caused by the increase in the separation of the points.

In the older type of arc lamp it was necessary to "trim" the lights by replacing the carbons every day; but recently lamps have been perfected in which the carbons last from one hundred to one hundred and twenty hours. In these the arc is enclosed in a glass globe which is made as nearly air-tight as possible with the necessary feed devices. This closed chamber is fitted with a valve opening outward, which allows the air to be forced out by the heat of the lamp, but does not admit a return current. In this manner a rarefied chamber is produced in which the carbons are oxidized very slowly; yet there is no diminution in the brilliancy of the light.

Early in the history of electric lighting it became apparent that the proper construction of the carbon electrodes was a highly important item in the manufacture of a lighting apparatus. The value of carbons depends largely upon their purity and freedom from ash in burning, and it required a countless number of experiments to develop the highly efficient carbons now in general use. Davy made use of pieces of wood charcoal in his experiments, but these were too fragile to be of practical value, even if their other qualities had been ideal. Later experimenters tried various compounds, and in 1876 Carré in France produced excellent carbons made of coke, lampblack, and syrup. From these were developed the present carbons, usually made by mixing some finely divided form of carbon, such as soot or lampblack made from burning paraffin or tar, with gum or syrup to form a paste. Rods of proper size and shape are made by forcing this paste through dies by hydraulic pressure, subsequently baking them at a high temperature. Sometimes they are given a coating of copper, a thin layer of the metal being deposited upon them by electrolysis.

EDISON AND THE INCANDESCENT LAMP

The familiar incandescent electric-light bulb seems such a simple apparatus to-day, being nothing apparently but a small wire enclosed in an ordinary glass bulb, that it is almost impossible to realize what an enormous amount of money, energy, and that particular quality of mentality which we call "genius" has been required to produce it. First and foremost among the names of the men of genius who finally evolved this lamp is that of Thomas A. Edison; and only second to this foremost name are those of Swan, Lane-Fox, and Hiram Maxim. But Edison's name must stand preeminent; and there are probably very few, even among Europeans, who would attempt or wish to deny him the enviable place as the actual perfecter of the incandescent-light bulb.

It is said that Edison first conceived the idea of an incandescent electric light while on a trip to the Rocky Mountains in company with Draper, in 1878. Be this as it may, he certainly set to work immediately after completing this journey, and never relaxed or ceased his efforts until a practical incandescent lamp had been produced. His idea was to perfect a lamp that would do everything that gas could do, and more; a lamp that would give a clear, steady light, without odor, or excessive heat such as was given by the arc lights—in short, a household lamp.

Early in his experiments he abandoned the voltaic arc, deciding that a successful lamp must be one in which incandescence is produced by a strong current in a conductor, the heat caused by the resistance to the current producing the glow and light. But when search was made for a suitable substance possessing the necessary properties to be the incandescent material, the inventor was confronted by a vast array of difficulties. It was of course essential that the substance must remain incandescent without burning, and at the same time offer a resistance to the passage of the current precisely such as would bring about the heating that produced incandescence. It should be infusible even under this high degree of heat, or otherwise it would soon disappear; and it must not be readily oxidizable, or it would be destroyed as by ordinary combustion. It should also be of material reducible to a filament as fine as hair, but capable of preserving a rigid form. These, among others, were the qualities to be considered in selecting this apparently simple filament for the incandescent lamp. It was not a task for the tyro, therefore, that Edison undertook when he began his experiments for producing an "ideal lamp."

The substance in nature that seemed to possess most of the necessary qualities just enumerated was the metal platinum, and Edison began at once experimenting with this. He made a small spiral of very fine platinum wire, which he enclosed in a glass globe about the size of an ordinary baseball. The two ends of the wires connected with outside conducting wires, which were sealed into the base of the bulb. The air in the bulb had to be exhausted and a vacuum maintained to diminish the loss of heat and of electricity and to prevent the oxidation of the platinum. But when the current was passed through the spiral wire in this vacuum a peculiar change took place in the platinum itself. The gases retained in the pores of the metal at once escaped, and the wire took on such peculiar physical properties that it was supposed for a time by some physicists that a new metal had been produced. The metal acquired a very high degree of elasticity and became susceptible of a high polish like silver, at the same time becoming almost as hard as steel. It also acquired a greater calorific capacity so that it could be made much more luminous without fusing. To diminish the loss of heat the wire was coated with some metallic oxide, and the slope of the spiral also aided in this as each turn of the spiral radiated heat upon its neighbor, thus utilizing a certain amount that would otherwise have been lost. But despite all this, Edison found, after tedious experimenting, that platinum did not fulfil the requirements of a practical filament for his lamp; it either melted or disintegrated in a short time and became useless; and the other experimenters had met with the same obstacles to its use, and were forced to the same conclusion.

Some other substance must be found. The use of carbon for arc lights and Edison's own experiments with carbon in his work on the telephone naturally suggested this substance as a possibility. It is said that this idea was brought forcibly to the inventor's attention by noticing the delicate spiral of vegetable carbon left in his hand after using a twisted bit of paper, one day, for lighting a cigar. This spiral of carbon was, of course, too fragile to be of use in its ordinary form. But it occurred to Edison that if a means of consolidating it could be found, there was reason to hope that it would answer the purpose. Experiments were begun at once, therefore, not only with processes of consolidation but also with various kinds of paper, and neither effort nor expense was spared to test every known variety of paper. Moreover, many new varieties of paper were manufactured at great expense from substances having peculiar fibres. One of these, made from a delicate cotton grown on some little islands off South Carolina, gave a carbon free from ash, and seemed to promise good results; but later it was found that the current of electricity did not circulate through this substance with sufficient regularity to get protracted and uniform effects. Nevertheless, since many things pointed to this fibre carbon as the ideal substance, Edison set about determining the cause of the irregularity in the circulation of the current in the filament, and a number of other experimenters soon became interested in the problem.

It was soon determined that the arrangement of the fibres themselves were directly responsible for the difficulty. In ordinary paper the fibres are pressed together without any special arrangement, like wool fibres in felting. In passing through such a substance, therefore, the current cannot travel along a continuous fibre, but must jump from fibre to fibre, "like a man crossing a brook on stepping-stones." Each piece of fibre constitutes a lamp or miniature voltaic arc, so that the current is no longer a continuous one; and the little interior sparks thus generated quickly destroy the filament. This discovery made it apparent that such an artificial, feltlike substance as paper could not be made to answer the purpose, and Edison set about searching for some natural substance having fibres sufficiently long to give the necessary homogeneity for the passage of the current.

For this purpose specimens of all the woods and fibre-substances of all countries were examined. Special agents were sent to India, China, Japan, South America, in quest of peculiar fibrous substances. The various woods thus secured were despatched to the Edison plant at Menlo Park and there carefully examined and tested. Without dwelling on the endless details of this tedious task, it may be said at once that only three substances out of all the mass withstood the tests reasonably well. Of these, a species of Japanese bamboo was found to answer the purpose best. Thus the practical incandescent lamp, which had cost so much time, ingenuity, and money, came into existence, fulfilling the expectation of the most sanguine dream of its inventor.

In using these bamboo carbon filaments the original spiral form of filament was abandoned, the now familiar elongated horseshoe being adopted, as the carbon could not be bent into the tortuous shapes possible with platinum. Later various modifications in the shape of the filament were made, usually as adaptations to changes in the shape of the bulbs.

At the same time that Edison was succeeding with his bamboo carbon filaments, J. W. Swan had been almost as successful with a filament formed by treating cotton thread with sulphuric acid, thus producing a "parchmentized thread," which was afterwards carbonized. A modification of this process eventually supplanted the Edison bamboo filament; and the filament now in common use—the successor of the "parchmentized thread"—is made of a form of soluble cellulose prepared by dissolving purified cotton wool in a solution of zinc chloride, and then pressing the material out into long threads by pressing it through a die.

The long thread so obtained is a semi-transparent substance, resembling catgut, which when carbonized at a high temperature forms a very elastic form of carbon filament. To prepare the filament the cellulose threads are cut into the proper lengths, bent into horseshoe shape, double loops, or any desired form, and then folded round carbon formers and immersed in plumbago crucibles. On heating these crucibles to a high temperature the organic matter of the filaments is destroyed, the carbon filaments remaining. These filaments are then ready for attachment to the platinum leading-in wires, which is accomplished either by means of a carbon cement or by a carbon-depositing process. They are then placed in the glass bulbs and the wires hermetically sealed, after which the bulbs are exhausted, tested, fitted with the familiar brass collars, and are ready for use.

The combined discoveries of all experimenters had made it evident that certain conditions were necessary to success, regardless of the structure of the carbon filament. It was essential that the vessel containing the filament should be entirely of glass; that the current should be conveyed in and out this by means of platinum wires hermetically sealed through the glass; and that the glass globe must be as thoroughly exhausted as possible. This last requirement proved a difficult one for a time, but by improved methods it finally became possible to produce almost a perfect vacuum in the bulbs, with a corresponding increase in the efficiency of the lamps.

THE TUNGSTEN LAMP

For twenty years the carbon-filament lamp stood without a rival. But meanwhile the science of chemistry was making rapid strides and putting at the disposal of practical inventors many substances hitherto unknown, or not available in commercial quantities. Among these were three metals, osmium, tantalum, and tungsten, and these metals soon menaced the apparently secure position of the highly satisfactory, although expensive, Edison lamp.

It will be recalled that the early experimenters had used two metals, platinum and iridium, for lamp filaments; and that these two, although unsatisfactory, were the only ones that had given even a promise of success. But in 1898 Dr. Auer von Welsbach took out patents, and in 1903 produced a lamp using an osmium filament. Its advent marked the beginning of the return to metal-filament lamps, although the lamp itself did not prove to be very satisfactory and was quickly displaced by a lamp invented by Messrs. Siemens and Halske, having a tantalum filament. On account of its ease to manufacture, its brilliant light, and relatively low consumption of power, this lamp gained great popularity at once, and for a single year was practically without a rival. Then, in 1904, patents were taken out by Just and Hanaman, Kuzel, and Welsbach, for lamps using filaments of tungsten, and the superiority of these lamps over the tantalum lamps gave them an immediate popularity never attained by either of the other metal-filament lamps.

Needless to say there is good ground for this popularity, which may be explained by the simple statement that the tungsten lamp gives more light with much less consumption of power per candle power than any of its predecessors. Unlike the carbon filament, which projects in the familiar elongated horse-shoe loop, or double loop, into the exhausted bulb, the tungsten filament is wound on a frame, so that several filaments (usually eight or more) are used for producing the light in each bulb. The chief defect of this lamp is the fragility of the filament, which breaks easily when subjected to mechanical vibration. On the other hand, tungsten lamps can be used in places at a long distance from the central generating plant, where the electric current is too weak for carbon-filament lamps.

THE MERCURY-VAPOR LIGHT OF PETER COOPER HEWITT

"On an evening in January, 1902, a great crowd was attracted to the entrance of the Engineers' Club in New York city. Over the doorway a narrow glass tube gleamed with a strange blue-green light of such intensity that print was easily readable across the street, and yet so softly radiant that one could look directly at it without the sensation of blinding discomfort which accompanies nearly all brilliant artificial lights. The hall within, where Mr. Hewitt was making the first public announcement of his great discovery, was also illuminated by the wonderful new tubes. The light was different from anything ever seen before, grateful to the eyes, much like daylight, only giving the face a curious, pale-green, unearthly appearance. The cause of this phenomenon was soon evident; the tubes were seen to give forth all the rays except red,—orange, yellow, green, blue, violet,—so that under its illumination the room and the street without, the faces of the spectators, the clothing of the women, lost all their shades of red; indeed, changing the face of the world to a pale green-blue.

"The extraordinary appearance of this lamp and its profound significance as a scientific discovery at once awakened a wide public interest, especially among electricians who best understood its importance. Here was an entirely new sort of electric light. The familiar incandescent lamp, though the best of all methods of illumination, is also the most expensive. Mr. Hewitt's lamp, though not yet adapted to all the purposes served by the Edison lamp, on account of its peculiar color, produces eight times as much light with the same amount of power. It is also practically indestructible, there being no filament to burn out; and it requires no special wiring. By means of this invention electricity, instead of being the most costly means of illumination becomes the cheapest—cheaper even than kerosene. No further explanation than this is necessary to show the enormous importance of this invention."

As just stated, the defect of the Edison incandescent lamp is its cost, due to its utilizing only a small fraction of the power used in producing the incandescence, and, of much less importance, the relatively short life of the filament itself. Only about three per cent. of the actual power is utilized by the light, the remaining ninety-seven per cent. being absolutely wasted; and it was this enormous waste of energy that first attracted the attention of Mr. Hewitt, and led him to direct his energies to finding a substitute that would be more economical. A large part of the waste in the Edison bulb is known to be due to the conversion of the energy into useless heat, instead of light, as shown by the heated glass. Mr. Hewitt attempted to produce a light that would use up the power in light alone—to produce a cool light, in short.

Instead of directing his efforts to the solids, Mr. Hewitt turned his attention to gaseous bodies, believing that an incandescent gas would prove the more nearly ideal substance for a cool light. The field of the passage of electricity through gases was by no means a virgin one, but was nevertheless relatively unexplored: and Mr. Hewitt was, therefore, for the most part obliged to depend upon his own researches and experiments. In these experiments hundreds of gases were examined, some of them giving encouraging results, but most of them presenting insurmountable difficulties. Finally mercury vapor was tried, with the result that the light just referred to was produced.

The possibilities of mercury-vapor gas had long been vaguely suspected—suspected, in fact, since the early days of electrical investigation, two centuries before. The English philosopher, Francis Hauksbee, as early as 1705 had shown that light could be produced by passing air through mercury in an exhausted receiver. He had discovered that when a blast of air was driven up against the sides of the glass receiver, it appeared "all round like a body of fire, consisting of an abundance of glowing globules," and continuing until the receiver was about half full of air. Hauksbee called this his "mercurial fountain," and although he was unable to account for the production of this peculiar light, which he remarked "resembled lightning," he attributed it to the action of electricity.

Between Hauksbee's "mercurial fountain" and Hewitt's mercury-vapor light, however, there is a wide gap, and, as it happened, this gap is practically unbridged by intermediate experiments, for Mr. Hewitt had never chanced to hear anything of Hauksbee's early experiments, or of any of the tentative ones of later scientists. But this, on the whole, may have been rather advantageous than otherwise, as, being ignorant, he was perhaps in a more receptive state of mind than if hampered by false or prejudicial conceptions. Be this as it may, he began experimenting with mercury confined in a glass tube from which the air had been exhausted, the mercury being vaporized either by heating, or by a current of electricity. No results of any importance came of his numerous experiments for a time, but at last he made the all-important discovery that once the high resistance of the cold mercury was overcome, a comparatively weak current would then be conducted, producing a brilliant light from the glow of the mercury vapor. Here, then, was the secret of the use of mercury vapor for lighting—a powerful current of electricity for a fraction of a second passed through the vapor to overcome the initial resistance, and then the passage of an ordinary current to produce the light.

In practice this apparent difficulty in overcoming the initial resistance with a strong current is easily overcome by the use of a "boosting coil," which supplies the strong current for an instant, and is then shut off automatically, the ordinary current continuing for producing the light. The mechanism is hardly more complex than that of the ordinary incandescent light, but the current of ordinary strength produces an illumination about eight times as intense as the ordinary incandescent bulb of equal candle-power.

The form of lamp used is that of a long, horizontal tube suspended overhead in the room, a brilliant light being diffused, which, lacking the red rays of ordinary lights, gives a bluish-green tone to objects, and a particularly ghastly and unpleasant appearance to faces and hands, as referred to a moment ago. In many ways this feature of the light is really a peculiarity rather than a defect, and for practical purposes in work requiring continued eye-strain the absence of the red rays is frequently advantageous. In such close work as that of pen-drawing, for example, some artists find it advantageous to use globes filled with water tinted a faint green color, placed between the lamps and their paper, the effect produced being somewhat the same as that of the mercury-vapor light. For such work the absence of the red rays of the Hewitt light would not be considered a defect; and in workshops and offices where Mr. Hewitt's lamps are used the workmen have become enthusiastic over them.

On the other hand, the fact that the color-values of objects are so completely changed makes this light objectionable for ordinary use; so much so, in fact, that the inventor was led to take up the problem of introducing red rays in some manner so as to produce a pure white light. He has partly accomplished this by means of pink cloth colored with rhodium thrown around the glass; but this causes a distinct loss of brilliancy.

The most natural method of introducing the red rays, it would seem, would be to use globes of red glass; but a moment's reflection will show that this would not solve the difficulty. Red glass does not change light waves, but simply suppresses all but the red rays; and since there are no red rays in the mercury-vapor light the result of the red globe would be to suppress all the light. Obviously, therefore, this apparently simple method does not solve the difficulty; but those familiar with Mr. Hewitt's work will not be surprised any day to hear that he has finally overcome all obstacles, and produced a perfectly white light. In the meantime the relatively expensive arc light and the incandescent bulb with its filament of carbon or metal hold unchallenged supremacy in the commercial field.

XII

THE MINERAL DEPTHS

AGES before the dawn of civilization, primitive man had learned to extract certain ores and metals from the earth by subterranean mining. Such nations as the Egyptians, for example, understood mining in most of its phases, and worked their mines in practically the same manner as all succeeding nations before the time of the introduction of the steam engine. The early Britons were good miners and the products of their mines were carried to the Orient by the Phœnicians many centuries before the Christian era. The Romans were, of course, great miners, and remains of the Roman mines are still in existence, particularly good examples being found in Spain.

Even the aborigines of North America possessed some knowledge of mining, as attested by the ancient copper mines in the Lake Superior region, although by the time of the discovery of America, and probably many centuries before, the interloping races of Indians who had driven out or exterminated the Lake Superior copper mines had forgotten the art of mining, if indeed they had ever learned it. But the fact that their predecessors had worked the copper mines is shown by the number of stone mining implements found in the ancient excavations about Lake Superior, these implements being found literally by cart loads in some places.

The great progress in mining methods, however, as in the case of most other mechanical arts, began with the introduction of steam as a means of utilizing energy; and another revolution is in rapid progress owing to the perfection of electrical apparatus for furnishing power, heat, and light. Methods of mining a hundred years ago were undoubtedly somewhat in advance of the methods used by the ancients; but the gap was not a wide one, and the progress made by decades after the introduction of steam has been infinitely greater than the progress made by centuries previous to that time.

This progress, of course, applies to all kinds of mines and all phases of mining; but steam and electricity are not alone responsible for the great nineteenth-century progress. Geology, an unknown science a century ago, has played a most active and important part; and chemistry, whose birth as a science dates from the opening years of the nineteenth century, is responsible for many of the great advances.

Obviously a very important feature of any mine must be its location, and the determination of this must always constitute the principal hazard in practical mining. Prospecting, or exploring for suitable mining sites, has been an important occupation for many years, and has in fact become a scientific one recently. Formerly mines were frequently stumbled upon by accident, but such accidental discoveries are becoming less and less frequent. The prospector now draws largely upon the knowledge of the scientist to aid him in his search. Geology, for example, assists him in determining the region in which his mines may be found, if it cannot actually point out the location for sinking his shaft; and at least a rough knowledge of botany and chemistry is an invaluable aid to him. It is obvious that it would be useless to prospect for coal in a region where no strata of rocks formed during the Carboniferous or coal-forming age are to be found within a workable distance below the surface of the earth. The prospector must, therefore, direct his efforts within "geological confines" if he would hope to be successful, and in this he is now greatly aided by the geological surveys which have been made of almost every region in the United States and Europe.

An example of what science has done in this direction was shown a few years ago in a western American town during one of the "oil booms" that excited so many communities at that time. In the neighborhood of this town evidences of oil had been found from time to time—some of them under peculiar and suspicious circumstances, to be sure—and the members of the community were in an intense state of excitement over the possibility of oil being found on their lands. Prices of land jumped to fabulous figures, and the few land-owners that could be induced to part with their farms became opulent by the transactions. An "oil expert" appeared upon the scene about this time—just "happening to drop in"—who declared, after an examination, that the entire region abounded in oil. He backed up his assertion by offering to stake his experience against the capital of a company which was formed at his suggestion. Before any wells were actually started, however, a prudent member of the company consulted the State geologist on the subject, receiving the assurance that no oil would be found in the neighborhood. Strangely enough the word of the man of science triumphed over that of the "oil expert," and although some tentative borings were made on a minor scale, no great amount of money was sunk. It developed afterwards that the evidences of oil found from time to time had been the secret work of the "expert."

In general, prospecting for oil differs pretty radically from prospecting for most other minerals. A very common way of locating an ore-mine is by the nature of the out-crop,—that is, the broken edges of strata of rocks protruding from hillsides, or tilted at an angle on level areas. If the ore-bearing vein is harder than the surrounding strata it will be found as a jutting edge, protruding beyond the surface of the other layers of rocks which, being softer, are more easily worn away. On the other hand, if this stratum is soft or decomposable it will show as a depression, or "sag" as it is called. Of course such protrusions and depressions may only be seen and examined where the rocks themselves are exposed; vegetation, drift, and snow preventing such observations. But the vegetation may in itself serve as a guide to the experienced prospector in determining the location of a mine, peculiar mineral conditions being conducive to the growth of certain forms of vegetation, or to the arrangement of such growth. Alterations in the color of the rocks on a hillside are also important guides, as such discolorations frequently indicate that oxidizable minerals are located above.

In hilly or mountainous regions, where the underlying rocks are covered with earth, portions of these surfaces are sometimes uncovered by the method known as "booming." In using this method the prospector selects a convenient depression near the top of a hill and builds a temporary dam across the point corresponding to the lowest outlet. When snow and rain have turned the basin so formed into a lake, the dam is burst and the water rushing down the hillside cuts away the overlying dirt, exposing the rocks beneath. This method is effective and inexpensive.

The beds of streams, particularly those in hilly and mountainous regions, are fertile fields for prospecting, particularly for precious metals. Stones and pebbles found in the bed are likely to reveal the ore-foundations along the course of the stream, and the shape of these pebbles helps in determining the approximate location of such foundations. An ore-bearing pebble, well worn and rounded, has probably traveled some little distance from its original source, being rounded and worn in its passage down the stream. On the other hand, if it is still angular it has come a much shorter distance, and the prospector will be guided accordingly in his search for the ore-vein.

But prospecting is not limited to these simple surface methods. In enterprises undertaken on a large scale, borings are frequently made in regions where there are perhaps no specific surface indications. In such regions a shaft may be sunk or a tunnel may be dug, and the condition of the underlying strata thus definitely determined. This last is, of course, a most expensive method, the simpler and more usual way being that of making borings to certain depths. The difficulty with such borings is that rich veins may be passed by the borer without detection; or, on the other hand, a small vein happening to lie in the same plane as the drill may give a wrong impression as to the extent of the vein.

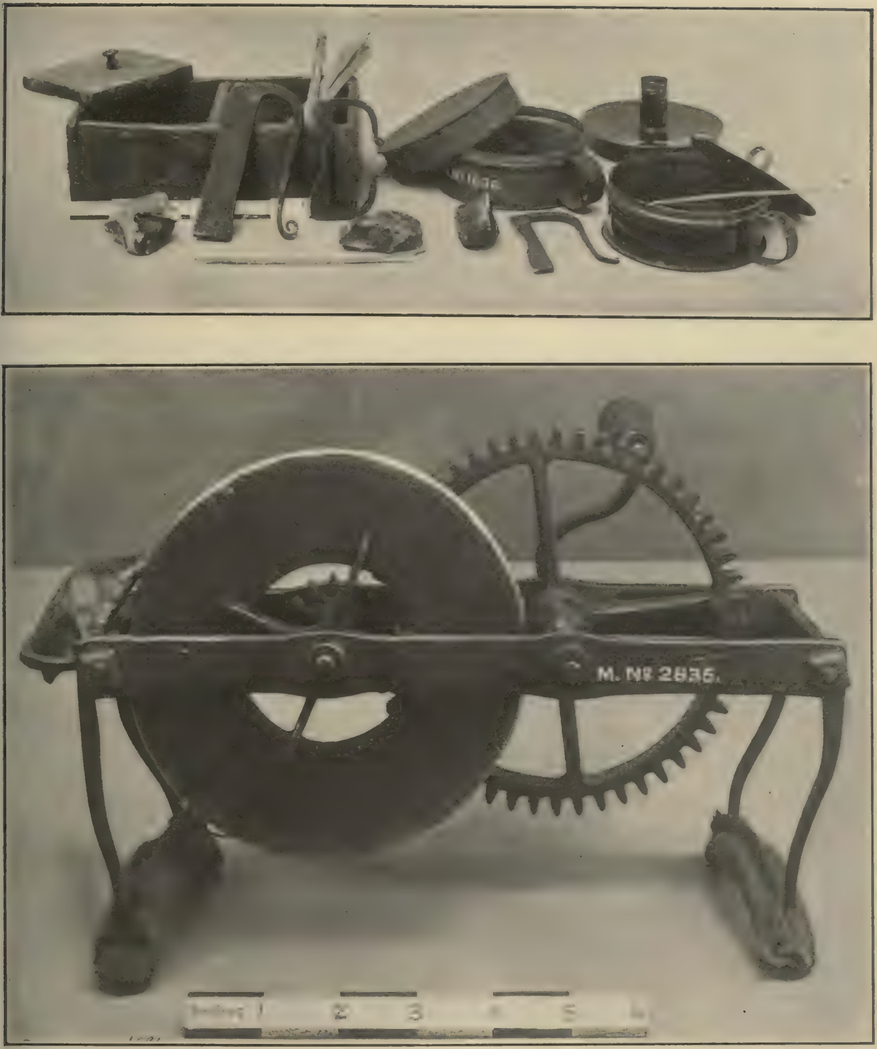
One of the most satisfactory ways of making borings is by means of the diamond drill. This drill is made in the form of a long metal tube, the lower edge of which is made into a cutting implement by black diamonds fixed in the edge of the metal. By rotating this tube a ring is cut through the layers of rock, the solid cylinder or core of rock remaining in the hollow centre of the drill. This can be removed from time to time, the nature and thickness of the geological formation through which the drill is passing being thus definitely determined.

CONDITIONS TO BE CONSIDERED IN MINING

Three great problems always confront the mine operator—light, power, and ventilation. Of these ventilation is the most important from the workman's standpoint, although the problem of light is scarcely less so. Obviously a cavity of the earth where hundreds of men are constantly consuming the atmosphere and vitiating it, and where thousands of lights are burning, would become like the black hole of Calcutta in a few minutes if some means were not adopted to relieve this condition. But besides this vitiation of the atmosphere caused by the respiration of the men and the burning of lamps there are likely to be accumulations of poisonous gases in mines, that are even more dangerous. Of the two classes of dangerous gases—those that asphyxiate and those that explode or burn—it may be said in a general way that the suffocating or poisonous gases, such as carbonic acid, which is known as black damp, or choke damp, are more likely to occur in ore mines, while the explosive gases are found more frequently in coal mines.

Choke damp, which is a gas considerably heavier than the atmosphere, is usually found near the bottom of mines, running along declines and falling into holes in much the same manner as a liquid. It kills by suffocation, and, as it will not support combustion, it may be detected by lowering a lighted candle into a suspected cavity, the light being extinguished at once if the gas is present. To rid the cavity of it, forced ventilation is used where possible, the gas being scattered by draughts of fresh air. If this is impracticable, and the cavity small, the choke damp may be dipped out with buckets.

But the problem of the mining engineer is not so much to rid cavities of gas as to prevent its accumulation. In modern mining, with proper ventilation and



A FLINT-AND-STEEL OUTFIT, AND A MINER'S STEEL MILL

The upper picture shows a flint-and-steel outfit, the implements for lighting a fire before the days of matches. The lower picture shows a miner's steel mill, which was used for giving light in mines before the day of the safety-lamp. It consists of a steel disk which is rotated rapidly against a piece of flint, producing a stream of sparks. It was thought that such sparks would not ignite fire-damp—a belief which is now known to be erroneous.

drainage, there is comparatively little danger of extensive accumulation of this gas.

The danger from this choke damp, therefore, is one that concerns the individual workman rather than large bodies of men or the structure of the mine itself. With fire damp, however, the case is different, as an explosion of this gas may destroy the mine itself and all the workmen in it. It is, therefore, the most dreaded factor in mining, and is the one to which more attention has been directed than to almost any other problem.

This fire damp is a mixture of carbonic oxide and marsh gas which, being lighter than air, tends to rise to the upper part of the mines. For this reason explosions are more likely to occur near the openings of the mine, frequently entombing the workmen in a remote part of the mine even when not actually killing them by the explosion. As this gas is poisonous as well as explosive the miners who survive the explosion may succumb eventually to suffocation.

Previous to the year 1816 no means had been devised for averting the explosions of fire damp except the uncertain one of watching the flame of the candle with which the miner was working. On coming in contact with air mildly contaminated with fire damp the candle flame takes on a blue tint and assumes a peculiarly elongated shape which may be instantly detected by a watchful workman. But miners were, and still are, a proverbially careless class of men even where a matter of life and death is concerned, and too frequently gave no heed to the warning flame. But in 1816 Sir Humphrey Davy invented his safety lamp, a device that has been the means of saving thousands of lives, and which has not as yet been entirely supplanted by any modern invention.

In making his numerous experiments, Davy had observed that iron-wire gauze is such a good conductor of heat that a flame enclosed in such gauze could not pass readily through meshes to ignite a gas on the outside. He found by experiment that a considerable quantity of explosive gas might be brought into contact with the gauze surrounding a flame, and no explosion occur. At the same time this gas would give warning of its presence by changing the color of the flame. When a lamp was made with a surrounding gauze having seven hundred and eighty meshes to the square inch, it was found to give sufficient light and at the same time to be practically non-explosive in the presence of ordinary quantities of gas.

One would suppose that such a life-saving invention would have been eagerly adopted by the men whose lives it protected; but, as a matter of fact, owing to certain inconveniences of Davy's lamps, many miners refused to use them until forced to do so by the mine-owners. One of these disadvantages was that this safety lamp gave a poor light overhead. This is particularly annoying to the miner, who wishes always to watch the condition of the ceiling under which he is working. When not under constant observation, therefore, a miner would frequently remove the gauze of the lamp and work by the open flame, regardless of consequences. Or again, he would sometimes forgetfully use the flame for lighting his pipe. To overcome the possibility of such forgetfulness or wilful disobedience, it was found necessary to equip safety lamps with locking devices, so that the miner had no means of access to the open flame of his lamp once it had been lighted.

Since the time of the first Davy safety lamp there have been numerous improvements in mechanical details, although the general principle remains unchanged. One of these improvements is a device whereby the lamp, when accidentally extinguished, may be relighted without opening it, and without the use of matches. This is done by means of little strips of paper containing patches of a fulminating substance which is ignited by friction, working on the same principle as the paper percussion caps used on toy pistols.

But even the improved safety lamp seems likely to disappear from mines within the next few years, now that electricity has come into such general use. As yet, however, no satisfactory portable electric lamp or lantern has been perfected, such lamps being as a rule too heavy, expensive, and unreliable. Even if these defects were remedied, the advantage would still lie with the Davy lamp, since the electric lamp, being enclosed, cannot be used for the detection of fire damp. But this advantage of the safety lamp is becoming less important, since well-regulated mines are now more thoroughly ventilated, and the danger from fire damp correspondingly lessened.

In some Continental mines the experiment has been tried of constantly consuming the fire damp, before it has had time to accumulate in explosive quantities, by means of numerous open lights kept constantly burning. This method is effective, but since the numerous lights consume the precious oxygen of the air as well as the damp, the method has never become popular. Obviously, then, the question of mine ventilation is closely associated with that of lighting.

Probably the simplest method of properly ventilating a mine is that of having two openings at the surface, one on a much higher level than the other if the mine is on a hillside, the lower one corresponding to the lowest portion of the mine where possible. By such an arrangement natural currents will be established, and may be controlled and distributed through the mine by doors or permanent partitions, or aided by fans. But of course only a comparatively small number of mines are so situated that this system can be used.

It is possible, of course, to ventilate a mine from a single shaft or opening by use of double sets of pipes, one for admitting air and the other for expelling it; but this system is obviously not an ideal one, and is prohibited by law in most mining districts. Such laws usually stipulate that there must be at least two openings situated at some distance from each other.

The older method of creating air currents was by means of furnaces, but this method, while very effective, is expensive and dangerous. In using this system a furnace is built near the outlet of the air shaft, the combustion of the fuel creating the necessary draught. But in the nature of things this furnace is a constant menace to the mine, besides being an extremely wasteful expenditure of energy. The modern method of ventilating is by means of rotary fans, the electric fan having practically solved the problem. The air currents established by such fans are controlled either by the doors in the passages, or by means of auxiliary fans. In addition, jets of compressed air are sometimes used, and have become very popular.

Another important problem that constantly confronts the mining engineer is that of drainage. Mines are, of course, great reservoirs for the accumulation of water, which must be drained or pumped out continually; and as the shafts are sunk deeper and deeper it becomes increasingly difficult to raise the water to the surface. Special means and machinery are employed for this purpose which will be considered more in detail in a moment.

ELECTRIC MACHINERY IN MINING

Electricity is, of course, the great revolutionary factor in modern mining. There is scarcely a department of mining in which electric power has not wrought revolutionary changes in recent years; and the subject has become so important and so thoroughly specialized as to "create a literature and a technology of its own." From the electric drill, working hundreds of feet below the surface of the earth, to the delicate testing-instruments in the laboratory of the assaying offices, the effect of this electrical revolution is being felt progressively more and more every year.

Moreover, electricity, on account of its transmutability, has made accessible many important mining sites hitherto unworkable. Rich mines are now in operation on an economical basis which, thirty years ago, were worthless on account of their isolation. When such mines were situated in mountainous regions where there was no coal supply at hand for creating steam power, and where the only available water power was perhaps several miles away, operations on a paying basis were out of the question before the era of electric power.

At present, however, the question of distance of the seat of power has been practically eliminated by the possibilities of electric conduction. A stream, situated miles away, when harnessed to a turbine and electric motors may afford a source of power more economical than could be furnished a few years ago by a power plant supplied with fuel at the very door of the mine. We need not enter into the details of this transmission of power, however, since the subject has been discussed in a general way in another place. Our subject here is rather to deal with the application of electricity to certain mining implements of special importance.

One of the most useful acquisitions to the equipment of the modern miner is a portable mechanical drill, which makes it possible for him to dispense with the time-honored pick, hammer, and hand-drill. But it is only recently that inventors have been able to produce this implement. The great difficulty has lain in the fact that a reciprocating motion, which is essential for certain kinds of drilling, is not readily secured with electric power. The use of steam or compressed air for operating such reciprocating drills presents no mechanical difficulties, and the fact that power of this kind can be transmitted long distances by the use of flexible tubes made such drills popular for several years. But the cost of operating such drills is so much greater than that of the new electric drills that they are rapidly being replaced in mining work.

The first attempts to produce an electric drill with a reciprocating motion were so unsuccessful that inventors turned their attention to perfecting some rotary device. This proved more successful, and rotary drills, operating long augers and acting like ordinary wood-boring machines, are now used extensively for certain kinds of drilling. The more recent forms perform the same amount of work as the air drill, with a consumption of about one-tenth the power. Moreover, none of the energy is lost at high altitudes as in the case of air drills, and they are not affected by low temperatures which sometimes render the air drill inoperable. On the other hand, the air drill is a hardy implement, capable of withstanding very rough usage, whereas the electric drill is probably the more economical, as well as the more convenient drill of the two.

In certain kinds of mining, such as in the potash mines of Europe and the coal mines of America, these electric drills operating their long augers have been found particularly useful. The ordinary type of drill is so arranged that it can be operated at any angle, vertically or horizontally. The lighter forms are mounted on upright stands, with screws at the ends for fastening to the floor and roof, although the heavier types are sometimes mounted on trucks. The motor, which is not much larger or heavier than an ordinary fan motor, is fastened to the upright and is from four to six horse-power. This connects with a flexible wire which transmits the power from the generating station, frequently several miles away. The auger, which is about the largest part of the machine and entirely out of proportion to the little motor that drives it, is simply a long bar of steel, twisted spirally at the cutting-end like an ordinary wood auger.

From the workman's standpoint these rotary drills are infinitely superior to reciprocating or percussion drills, where the constant jarring of the machine, besides being extremely tiresome, sometimes produces the serious disease known as neuritis. Various means have been attempted to prevent this, such as by overcoming the jar in a measure by flexible levers which do not transmit the vibrations to the hands and arms; but such attempts are only partially successful, and a certain amount of jarring cannot be avoided. In the rotary electric drills there is none of this, the workmen simply controlling the drill and the motor with levers, and receiving at most only a slight jar from the vibrations of the auger.

TRACTION IN MINING

In recent years electric traction engines for use in mines have been rapidly replacing horse- and mule-power, and have become important economic factors in mining operations. The pioneer of this type of locomotive seems to have been one built by Mr. W. M. Schlessinger for one of the collieries of the Pennsylvania Railroad about 1882, and which has remained in active use ever since. The total weight of this locomotive was five tons and it was equipped with thirty-two horse-power electric motors. The current was supplied through a trolley pole which took the current from a T-shaped rail placed above and at one side of the track. The train hauled by this locomotive consisted of fifteen cars, carrying from two to three tons of coal each.

Following this first mining-locomotive a great number were quickly produced. In Pennsylvania alone something like four hundred are now in use, and in Illinois two million tons of coal were hauled in this manner in twelve mines in 1901. It was estimated at the beginning of the present century that some 3,000 electric locomotives specially built for mining were in use in the United States alone.

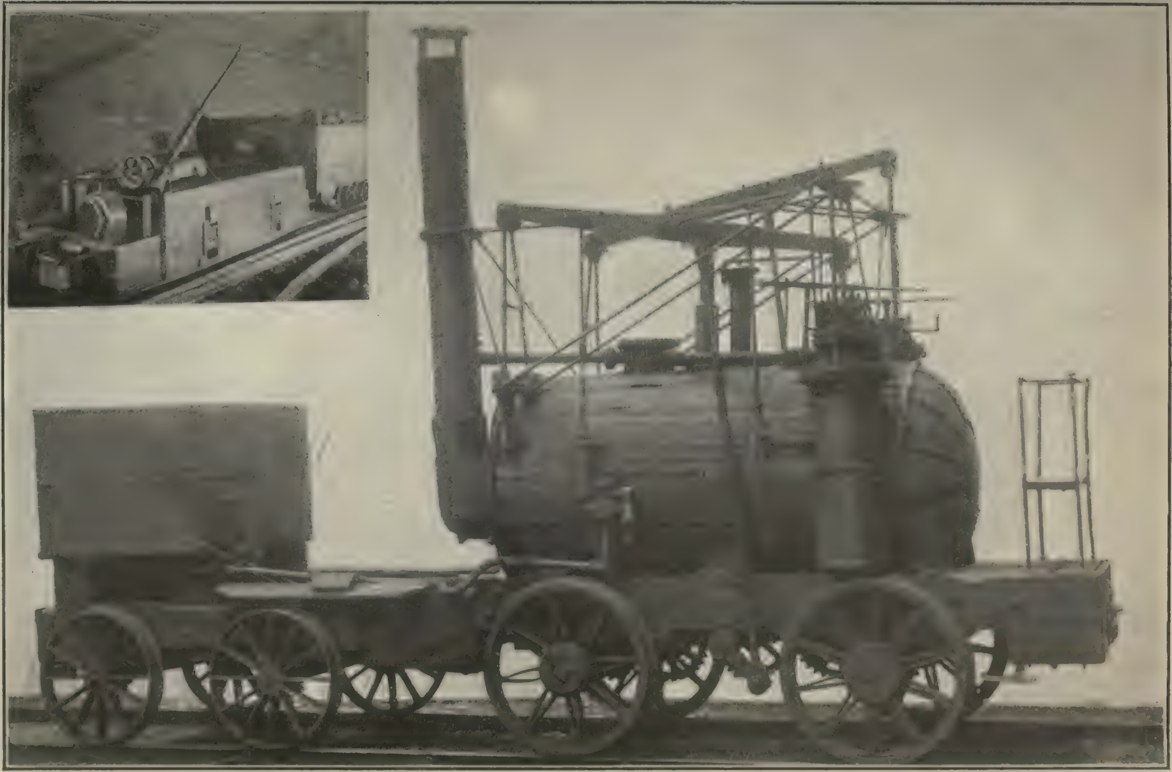
The earlier types of mining-locomotives were much higher and bulkier than those of more recent construction, the motors being mounted above the trucks and geared downward. Very soon, however, the "turtle-back" or "terrapin-back" type was developed, with the motors brought close to the ground, so that even quite a heavy locomotive might not be much higher than the diameter of its driving-wheels. When these queer-looking machines were boxed in so that even the wheels were covered, they lost all resemblance to locomotives or vehicles of any kind, appearing like low, rectangular metal boxes placed upon the car tracks, that glided along the rails in some mysterious manner. The presence of the trolley pole helped to dispel this illusion, but in some instances this is wanting, the power being taken from a third rail.

With these locomotives, some of them not more than two and a half feet high, it was possible to haul trains even in very low and narrow passages—much lower, in fact, than could be entered by the little mules used in former years. This in itself was revolutionary in its effects, as many thin veins were thus made workable.

This type of low locomotive is the one that has come into general use throughout the world. Such locomotives range in size from two to twenty tons, with wheel gauges from a foot and a half wide to the standard railway gauge of four feet, eight and a half inches. Locomotives weighing more than twenty tons are not in general use on account of the small size of the mine entrances.

In the ordinary types the motorman sits in front, controlling the locomotive with levers and mechanical brakes placed within easy reach, but sunk as low as possible. As a rule, the motors are geared to the truck axles, either inside or outside the locomotive frame. An overhead copper wire supplies the current by contact with a grooved trolley wheel mounted on the end of the regulation trolley pole. An electric headlight is used, and the ordinary speed attained by the compact motors is from six to ten miles an hour.

The amount of work that can be performed by one of these little, flat, box-like locomotives is entirely out of proportion to its size. A 10-ton locomotive in a



THE LOCOMOTIVE "PUFFING BILLY" AND A MODERN COLLIERY TROLLEY.

This locomotive was constructed in 1813 at Wylam Colliery, England, by William Hedley. It was entirely successful, and was in operation for almost half a century, up to the time of its removal in 1862 to the South Kensington Museum. The vertical cylinders and arrangement of walking beams for transmitting power are particularly interesting. The power was transmitted through cogged wheels to the rear axle, as is done with modern automobiles.

Pennsylvania mine hauled about 150,000 tons of coal in a year at a cost of less than one-tenth of a cent per ton for repairs. The usual train was made up of thirty-five cars, each loaded with about 3,700 pounds of coal, which was hauled up a three-per-cent grade. The cost of such haulage was only about 2.76 cents per ton, as against 7.15 cents when hauled by mule-power. These figures may be considered representative, as other mines show similar results.

A particular advantage has been gained by the use of electric locomotives over older methods in the process of "gathering" the cars. In many coal mines, even when the main hauling is done by electricity, the gathering or collecting of cars from the working faces of the rooms was formerly done either by mule-power or by hand. In some low-veined mines, hand power alone was used, on account of the low roof.

In such places, low, compressed-air locomotives were sometimes used; but these were very expensive. These have now been very generally replaced by "turtle-back" electric locomotives, operated at a distance from the main trolley wire by means of long, flexible cables, so geared that they can be paid out or coiled as desired.

On the main line these locomotives take the current from the trolley wire by means of the trolley pole, but when the place for gathering is reached, the connection is made by means of the flexible cable, and the trolley pole fastened down so as not to be in the way. This allows the locomotive to push the little cars into the rooms far removed from the main line, with passages too low and narrow to allow the use of the trolley pole. By the time the last cars have been delivered the first cars of the train have been filled, and the process of gathering may be begun at once, and the loaded train made up for the return trip. With such a locomotive two men can distribute and gather up from one hundred to one hundred and twenty cars in an ordinary eight-hour working-day, hauling from three hundred to three hundred and fifty tons of coal.

In certain regions, a system of third-rail current-supply is used, this rail being also a tooth rail with which a cog on the locomotive works frictionally. For climbing steep grades this system of cogged rails has many advantages over other systems.

Another type of electric locomotive used in some mines is a self-propelling or automobile one equipped with storage batteries. Such locomotives do away with the inconvenience and dangers of contact rails or trolley wires, but are heavy and expensive. A compromise locomotive, particularly useful for gathering, is one equipped with both trolley pole and storage batteries. This locomotive is so made that the storage batteries are charged while it is running with the trolley connection, so that no time is lost in the charging process. Such locomotives have been found very satisfactory for many purposes, and but for the imperfections common to all storage batteries would be ideal in many ways. They can be worked over any improvised track, regardless of distance, which is an advantage over the flexible-cable system where distances are limited by the length of cable; and the first cost of the battery is no more than the outlay on trolley wires and supports. It is also claimed that the cost of maintenance is relatively low, but it is doubtful if it equals the trolley or third-rail systems in this respect.

Closely allied to the systems of traction by electric locomotives, is the modern electric telpherage system. Until quite recently the haulage of ores and other raw materials used in mining, when done aerially, has been by means of travelling rope or cable. When distances to be travelled in this manner are short, such as across streams or valleys, where no supports are used, the term "cableway" is generally applied; but where the distance is so long that supports are necessary, the term "tramway cable" is used. It is to these longer systems that electric telpherage is particularly applicable.

The advantage of such an electric system over the older method is the same as the advantages of the trolley road over the cable, all ropes and cables being stationary, the electric motor, or "telpher," travelling along on one cable and taking its current by means of a trolley pole from a wire above. For heavier work metal rails supported between posts are employed in place of a flexible cable, and over such systems loads of several tons can be hauled.

Such an electric telpher system is used in one of the Cuban limestone quarries, the telpher and cars travelling a long distance upon cables, except at some of the curves, where solid rails are substituted, hauling a load of a thousand pounds at a speed of from twelve to fifteen miles an hour. The current comes from a distant source, and the telpher is so arranged that it travels automatically when the current is turned on, stopping when the current is cut off. This is quite a common arrangement for smaller telphers, but in the larger ones a man travels with the telpher and load, controlling the train just as in the case of the ordinary trolley system.

The various processes of hoisting in mines by electricity is closely akin to that of traction, since, after all, "an elevator is virtually a railway with a 100-per-cent grade." As such work is done spasmodically, long periods of rest intervening between actual periods of work, a great deal of energy is wasted by steam hoisting engines, where a certain pressure of steam in the boiler must be maintained at all times. For this reason electrical energy for hoisting has come rapidly into popularity in recent years. "The throttling of steam to control speed," said Mr. F. O. Blackwell in addressing the American Institute of Mining Engineers, "the necessity for reversing the engine, the variation in steam pressure, the absence of condensing apparatus, the cooling and large clearance of cylinders, and the condensation and leakage of steam pipes when doing no work, are all against the steam hoisting engine. One of the largest hoisting engines in the world was recently tested and found to take sixty pounds of steam per indicated horse-power per hour. The electric motor, on the other hand, is ideal for intermittent work. It wastes absolutely no energy when at rest, there being no leakage or condensation. Its efficiency is high, from one-quarter load to twice full load."

There seems to be practically no difference as far as the element of danger is concerned between steam and electric hoists. The difference is largely one of economy. The importance of this is shown by the recent comparisons in a gold mine which has replaced its steam apparatus by electricity. In this mine the hoist moves through the shaft at a rate of over twelve hundred feet per minute, elevating five hundred tons of ore daily on double-decked cages. It is estimated that this system shows an efficiency of 75 per cent, taking into account losses of all kinds, with a resulting reduction of cost of from seven to twenty dollars per horse-power per month.

Results comparing very favorably with these have been obtained also in some of the mines in Germany and Bohemia, where electricity has been introduced extensively in mining. In one of these mines the daily hoisting capacity is twenty-seven hundred tons from a depth of over sixteen hundred feet, at a speed of over fifty-two feet per second. In the Comstock mine, at Virginia City, Nev., electric hoists are used which obtain their power from a plant situated on the Truchee River thirty-two miles away.

ELECTRIC MINING PUMPS

In pumping, which is always one of the important items in mining, the use of electric power has been found quite as advantageous as in the other fields of its application. No special features are embodied in most of the types of mining pumps over the rotary and reciprocating types used for ordinary purposes, except perhaps a type of pump known as the sinking pump. This is a movable pump that can be easily lowered from one place to another, and has proved to be a great time-saver over steam or air pumps used for similar purposes.

For some time the question of the durability of electric pumps was in dispute, but developments in quite recent years seem to prove that, in some instances at least, such pumps are practically indestructible.

"The question of what would happen to an electric motor in a mine if pumps and motors get flooded has often come up. From tests made recently at the University of Liége, Belgium, it appears that a suitably designed polyphase alternating-current motor of a type largely used on the continent of Europe was completely submerged in water. It was run for a quarter of an hour; it was then stopped and allowed to remain submerged, under official seal, for twenty-four hours, at the end of which time it was again run for a few minutes. It was next removed from the water, again put under seal, and left to dry for twenty-four hours. The insulation was then tested, and the motor was found to be in perfect order. It would be hard to imagine a test more severe than this.

"As bearing upon this question it is interesting to note that among the pumps in use around Johannesburg, South Africa, at the beginning of the Anglo-Boer War, there were twelve of a well-known American make, each of which was operated by a 50-horsepower induction motor of American construction with three 15-kilowatt transformers. When the mines were shut down, upon the breaking out of the war, the water rose so rapidly that it was impossible to remove the pumps, motors, transformers, etc., and consequently they remained under 500 to 1,000 feet of water. Two and a half years later, when peace was declared in South Africa, the water in the shaft was pumped out and the electrical apparatus was removed to the surface. Three of the motors were stripped and completely rewound, but to the general surprise of the experts the condition of the insulation indicated that the rewinding might not be absolutely necessary. Accordingly the other nine motors were thoroughly dried in an oven and then soaked in oil. After this treatment they were rigidly tested, proved to be all right, and were at once restored to regular service in the mine. The transformers were treated in the same manner as the motors, with equally gratifying results.

"An interesting illustration of the flexibility and adaptability of electric motors for pumping purposes is furnished by the Gneisenau mine, near Dortmund, Germany, where a very large electric mining plant was installed in 1903. In this instance the pump is located more than 1,200 feet below the surface, and the difficulties of installing the apparatus were so great, on account of the small cross section of the shaft, that it was necessary to build up the motor in the pumping chamber, the material being transported through the wet shaft and the winding of the coils being performed *in situ*.

"An interesting use of the electric pump associated with the telephone in connection with mining is noted by Mr. W. B. Clarke. In one coal mine, where an electric pump is located in a worked-out portion of the mine, the circuits are so arranged that the pump is started from the power house, some distance away. Near the pump is placed a telephone transmitter connected to a receiver in the power house. To start the motors, or to ascertain whether the pumps are working properly, the engineer merely listens at the telephone receiver, without leaving his post."

ELECTRICITY IN COAL MINING

In coal mining the effect of the use of electrical machinery has been revolutionary in recent years, particularly in the development of electric coal cutters. The old method of picking out coal by hand, where the miner labored with the heavy pick, working in all manner of cramped and dangerous positions, was supplanted a few years ago by the "puncher" machine, worked by steam or compressed air. With these machines the coal was picked out just as in the case of the hand method, except that the energy was derived from some power other than muscular. So that while these machines worked more rapidly than the hand picks, they utilized the same general principle in applying their energy.

Within recent years, however, various coal-cutting machines have been devised, with which the coal was actually cut, or sawed out, these machines being peculiarly well adapted to using the electric current. The most practical and popular form of machine is one in which the sawing is done by an endless chain, the links of which are provided with a cutting blade. These have been very generally replacing the compressed-air or pick type of machine, and their popularity accounts largely for the enormous increase in the use of coal-mining machinery during the past decade. Thus in 1898 there were 2,622 coal-mining machines in use in the United States. Four years later this number had more than doubled, the increase being due largely to the adoption of chain machines.

Like electric locomotives, and for similar reasons, the coal-cutting machines are low, broad, flat machines, from eighteen to twenty-eight inches high. They rest upon a flat shoeboard that can be moved easily along the face of the coal. An ordinary machine weighs in the neighborhood of a ton, and requires two men to operate. The apparatus is described briefly as follows:

"On an outside frame, consisting of two steel channel bars and two angle irons riveted to steel cross ties, rests a sliding frame consisting of a heavy channel or centre rail, to which is bolted the cutter head. The cutter head is made entirely of two milled steel plates, which bolt together, forming the front guide for the cutter chain. This chain, which is made of solid cast steel links connected by drop forge straps, is carried around idlers or sprockets placed at each end of the cutter head and along the chain guides at the side to the rear of the machine, where it engages with and receives its power from a third sprocket, under the motor. The electric motor, which is of ironclad multipolar type, rests upon a steel carriage, which forms the bearing for the main shaft . . . A reversing switch is provided, so that the truck can travel in either direction, and when the machine has reached its stopping point, either forward or backward, it is checked by an automatic cut-off. The return travel is made in about one-fourth of the time required to make the cut."

In veins of coal of a thickness from twenty-eight to thirty inches, such a machine will cut about one hundred tons of coal in a day. The cost of production with such machines has been estimated at about sixty-three cents a ton, as against ninety cents as the cost of pick mining in rooms,—a saving of about twenty-seven cents a ton. Since it is estimated that for a cost of $10,000 an electrical equipment can be installed capable of working four such machines besides affording power for lighting, pumping, ventilation of the mine, etc., thus saving something like $100 a day for the operator, the great popularity of these machines is readily understood.

After such a machine has been placed in position, a cut some four feet wide, four or five inches high, and six feet deep can be made in five minutes, with the expenditure of very little energy on the part of the workmen. One of the largest cuttings ever recorded by one of these machines is 1,700 square feet in nine and one-half hours, although this may have been exceeded and not recorded.

Among the several advantages claimed for the chain machine over the older pick machines is the small amount of slack coal produced, and the absence of the racking vibrations that exhaust the workmen, and, like the air drills, sometimes cause serious diseases. On the other hand the advocates of the pick machines point out that they can be used in mines too narrow for the introduction of chain machines. They show also that there is a constant element of danger from motor-driven machines in mines where the quantity of gas present makes it necessary to use safety lamps, on account of the sparking of the machines which may produce explosions. Both these claims are valid, but apply only to special cases, or to certain mines, and do not affect the general popularity of the chain machines.

There are several different types of chain cutting machines, such as "long-wall machines," and "shearing machines," but these need not be considered in detail here. The general principle upon which they work is the same as the ordinary chain machine, the difference being in the method of applying it for use in special situations.

ELECTRIC LIGHTING OF MINES

For many obvious reasons the ideal light for mining purposes is one in which the danger from the open flame is avoided, particularly in well-ventilated mines, or mines under careful supervision, where the danger from inflammable gases is slight. The incandescent electric light, therefore, has become practically indispensable in modern mining operations. For certain purposes and in certain locations where an intense light is desirable and where there is no danger from combustible gases, arc lights are used to a limited extent. But there is constant danger from the open flame in using such lights, and also from the connecting wires leading to them. Furthermore, such intense light is not usually necessary in the narrow passages of the mine.

To be sure, there is a certain element of danger even with incandescent lights on account of the possibility of breakage of the globes, and of short-circuiting where improper wiring has been done. To overcome as much as possible the dangers from these sources, special precautions are taken in wiring mines, and special bulbs are used. In general the incandescent lamps as used in mining are made of stout round bulbs of thick glass which are not likely to crack from the effects of water dripping upon them while heated. As a further protection it is customary to enclose the bulbs in wire cages. It is also customary to use low-current lamps with a rather high voltage, although this must be limited, as excessive voltage may in itself become a source of danger.

XIII

THE AGE OF STEEL

THE iron industry has of late years become more and more merged into the steel industry, as steel has been gradually replacing the parent metal in nearly every field of its former usefulness. Steel is so much superior to iron for almost every purpose and the process of making it has been so simplified by Bessemer's discovery that it may justly be said that civilization has emerged from the Iron Age, and entered the Age of Steel. While iron is mined more extensively now than at any time in the history of the world, the ultimate object of most of this mining is to produce material for manufacturing steel. We still speak of boiler iron, railroad iron, iron ships, etc., but these names are reminiscent, for in the construction of modern boilers and modern ships, steel is used exclusively. In the past decade it is probable that no railroad rails even for the smallest and cheapest of tracks have been made of anything but steel.

The last half of the nineteenth century has been one of triumph of steel manufacture and production in America, and at the present time the United States stands head and shoulders above any other nation in this industry. In the middle of the century both

Germany and England were greater producers than America; but by the close of the century the annual output in the United States was above fifteen million tons as against England's ten and Germany's seven; and since 1900 this lead has been greatly increased. The steel industry has become so great, in fact, that it is "a sort of barometer of trade and national progress."

The great advances in the quantity of steel produced have been made possible by corresponding advances in methods of winning the iron ore from the earth. Mining machinery has been revolutionized at least twice during the last half century, first by improved machines driven by steam, and again by electricity and compressed air. Ore is still mined to a limited extent by men with picks and shovels, but these implements now play so insignificant a part in the process that they cannot be considered as important factors. Steam shovels, automatic loaders and unloaders, dynamite and blasting powder, have taken the place of brawn and muscle, which is now mostly expended in directing and guiding mining machinery rather than in actually handling the ore.

THE LAKE SUPERIOR MINES

At the present time the greatest iron-ore fields lie in the Lake Superior region, and it is in this region that the greatest progress in mining methods has been made in recent years. There are, of course, extensive mines in other sections of the United States, but at least three-quarters of all the iron produced in America comes from the Lake Superior mines, and the systems of mining pursued there may be considered as representative of the most advanced modern methods.

Where the iron ore of these mines is found near the surface of the earth, the great system of "open-pit" mining is practised; but as only a relatively small portion of the ore is so situated, modifications of older mining methods are still employed. Of these the three most important are known as "overhead scooping," "caving," and "milling."

In the overhead method a shaft is sunk into the earth to a depth of several hundred feet, according to the depth of the ore, this shaft being lined with timbers for support. From this shaft horizontal tunnels are made in all directions in the ore deposits, and through these tunnels the ore is conveyed to the shaft and thence to the surface. As the ore is removed and the earth thus honeycombed in all directions, supports of various kinds must be made to prevent caving. For this purpose columns of the ore itself may be left, or supports of masonry or wood or steel may be introduced. Under certain circumstances, however, these supports are not employed, the earth being allowed gradually to cave in at the surface as the ore is removed, this being the method of mining known as "caving."

Where the ore deposit occurs in a favorable hillside the "milling" system is frequently employed. In working this system a large horizontal tunnel, twenty or more feet in diameter, is dug into the hillside. Perpendicular shafts are then sunk from the top of the hill, connected with openings leading directly into the top of the main horizontal shaft. By this arrangement the ore, when loosened in these perpendicular shafts, falls directly into the bins placed for its reception about the openings, or into the rows of cars in waiting to receive it. In this method dynamite and powder take the place of hand labor, the main mass of ore being dislodged and thrown into the shaft by blasting, instead of by hand labor.

But all these methods are overshadowed in magnitude by the great "open pit" systems, where the ore is taken from the surface and handled entirely by machinery, the only part played by the miner's pick being that of assisting in loosing certain fragments so that they may be more easily seized by the machines. Indeed, this system of mining partakes of the nature of quarrying rather than that of mining in the ordinary sense, the ore being scooped from the surface of the ground. One naturally thinks of a mine as being subterranean; but in the great open-pit mines in the Lake Superior region, which are the largest mines in the world, all the mining is done at the surface of the earth.

It should not be understood, however, that in such mines nature has left the red iron ore exposed at the surface in any great quantities. On the contrary, it is usually covered by a layer of earth ranging from a yard to ten or more yards in depth, and this, of course, must be removed before open-pit methods can be practised. Prospecting for such deposits is therefore just as necessary as in cases where the deposit is situated much deeper in the earth; and the business of prospecting by "test pit" men is as important an industry as ever.

When an available open-pit mine of sufficient extent has been located the gigantic task of "stripping" or removing the overlying layer of earth begins. Immense areas of land have been thus stripped in some of these undertakings, no difficulties being considered insurmountable. If a small river-bed lies in an unfavorable position, the course of the river is changed regardless of expense. Farms and farm houses are purchased and literally carted away, neither land nor houses representing values worth considering when compared with the stratum of ore beneath them. The single contract for stripping one area in the Lake Superior region was let for a sum amounting to half a million dollars.

As soon as a sufficiently large area has been stripped, railroads are constructed into the pit, steam shovels are run into place, and the actual work of mining begins. Five shovels full make a car-load, and under ordinary circumstances the five loads may be delivered in as many minutes.

The number of men required to manipulate one of these steam shovels is from ten to twelve. The ore itself is frequently so hard that the scoop of the shovel could not penetrate it until loosened and broken up, and it is the business of the gang of workmen to do this and slide the ore down within easy working distance of the shovel. This is mostly done by blasting with dynamite and powder, little of the actual labor being performed by hand. In blasting, a deep hole is first drilled into the ore near the top of the embankment, and into this hole a stick of dynamite is dropped and exploded. This enlarges the cavity sufficiently so that a quantity of blasting powder may be poured in and set off, tumbling the ore down within reach of the shovel.

This ore is frequently almost as hard as iron itself, many of the pieces thus dislodged being too large for convenient handling, either by the steam shovel or in the chutes at the wharves, and must be still further broken up. This is sometimes done by the men with picks; but in mining on a large scale, where the deposit is all of a very hard nature, crushing machines are used.

In this manner the steam shovel is kept constantly supplied with ore for the waiting train of cars. These trains are arranged on a track running parallel with the track from which the steam shovel operates, and at such a distance that the centre of the car will be directly under the opening in the bottom of the shovel when it is swung around on its crane. The engineer in charge of the locomotive drawing the train stops it in a position so that the first shovelful of ore will be dumped into the forward end of the first car. As each successive shovelful is deposited, representing about one-fifth of a car-load, the train is pulled or backed along the track about one-fifth of a car-length. In this manner it is only necessary for the steam shovel to be swung into the same position and dumped at the same point each time to insure the proper loading of the cars.

From what has been said it will be seen that in this open-pit mining the steam engine and steam locomotive still play a conspicuous part; but in the other forms of iron mining, electric or compressed-air motors are used, as much better adapted for underground work. In the Lake Superior region, where everything is done by the most modern methods, the use of horses and mules for hauling purposes is practically unknown.

The cars used for hauling the ore are of peculiar construction. The latest types are built of steel with a carrying capacity of fifty tons of ore, and are so made that by simply knocking loose a few pins their bottoms open and discharge the ore into the receiving bins on the wharves, or into the chutes leading to the waiting boats.

A perennial problem in iron mining, whether surface or subterranean, just as in all other kinds of mining, is the removal of accumulations of water, some of these mines filling at the rate of from twenty-five to thirty thousand gallons an hour. But an equally important problem is that of removing moisture from the ore itself. Obviously every additional pound of moisture adds to the cost and difficulty in handling, and inasmuch as this ore must be transported a distance of something like a thousand miles, necessitating three or four handlings in the process, the aggregate amount of wasted energy caused by each ton of water is enormous. It has been found that at least ten per cent of the moisture may be dried out of the ore before shipping, and that the ore does not tend to absorb moisture again under ordinary circumstances once it has been dried.

This is of course of great advantage where it is found necessary to store it in heaps some little time before shipping.

FROM MINE TO FURNACE

In most industries, particularly where the percentage of waste products is large, it is found advantageous and economical to establish factories as near the source of supply of raw material as possible. But the iron ore mined in the Lake Superior region is transported something like a thousand miles before being delivered to the factories. The question naturally arises, Why is not the ore turned into pig iron or steel ingots at once as near the mouths of the mines as possible, and sent in this condensed form to the factories, thus saving more than half the cost of transportation? The answer is simple: the coal mines and steel factories lie in the East, one established by nature, the other by man many years before iron ore was found in the Lake region. And it is found just as cheap and easy to transport the iron to the coal regions as it would be to transport the coal to the ore regions. Furthermore, the factories in the neighborhood of Pittsburg and along the southern shores of Lake Erie and Lake Ontario are near the great centres of civilization, and are accessible the year round; while the Lake Superior region is "frozen in" for at least three months in the year.

And so, in place of a great traffic of coal westward to the Lake Superior regions, there is a great eastward traffic of ore, by rail and water, passing from the mines to furnaces and factories a thousand miles away. Indeed, this is probably the greatest and most remarkable system of transportation in the world. Specially constructed trains, wharves, boats, and machinery, used for this single purpose, and not duplicated either in design or extent, make this stupendous enterprise a unique, as well as a purely American one.

The transportation begins with the train loads of ore that run from the mines to the lake shore and out upon the wharves built to receive them. These wharves are enormous structures, sometimes half a mile in length, built up to about the height of the masts of ore boats. On the sides and in the centres of these towering structures are huge bins for holding the ore, these bins communicating directly with the holds of the ore steamers tied up alongside. Four tracks are frequently laid on the top of the wharves, and are so arranged that trains four abreast can dump the ore into the bins, or waiting ships, at the same time. If the bins are empty and boats waiting to receive a cargo, the ore is discharged by long chutes into the holds from the cars. Otherwise the bins are filled, the trains returning to the mines as quickly as possible for fresh loads.

The boats for receiving this cargo are of special design, many of them differing very greatly in appearance from ordinary ocean liners of corresponding size. This is particularly true of the "whale-backs" which have little in common in appearance with ordinary steamers except in the matter of funnels; and even these are misplaced sternwards to a distance quite out of drawing with the length of the hull. Their shape is that of the ordinary type of submarine boat—that is, cigar-shaped—this effect being obtained by a curved deck completely covering the place ordinarily occupied by a flat deck. A wheel-house, like a battle-ship's conning-tower, is placed well forward, supported on steel beams some distance above the curved deck for observation purposes; and engines, boilers, and coal bunkers occupy a small space in the stern. The boat, therefore, is mostly hold.

But the "whale-backs" form only a small portion of the ore-fleet. The ordinary type of boat conforms more nearly to the shape of ocean boats, except that the bridge, wheel-house, and engines are located as in the whale-backs. The bows of these boats are blunt, the desideratum in such craft being hull-capacity rather than speed. For sea-worthiness they are equal to any ocean boats, as the battering waves of Lake Superior are quite as powerful and even more treacherous than those of the Atlantic or Pacific. Some of these boats are five hundred feet long, equal to all but the largest ocean vessels. Their coal-carrying capacity is relatively small, since coaling stations are numerous at various points on the journey, and every available inch of space is utilized for the precious iron ore.

In order to facilitate loading, the decks are literally honey-combed with hatches, some boats having fifteen or sixteen openings extending the width of the deck. By this arrangement the time of loading is reduced to a matter of a few hours, as a dozen chutes, each discharging several tons of ore per minute, soon fill the yawning compartments with the necessary six, eight, or nine thousand tons, that make up the cargo.

Quite recently lake-navigators have learned, what rivermen have long known, that cheap transportation may be effected on a large scale by barges and towing. Before the outbreak of the Civil War forty years ago, the Mississippi river swarmed with great cargo-carrying steamers, employing armies of men and consuming enormous quantities of fuel. But after the war the experiment was tried of hauling the cargoes on barges towed by tug boats, and this proved to be so much cheaper that the fleet of great river boats soon disappeared. In somewhat the same way the barge has come into use of late years in the ore-traffic, and the great ore-steamers now tow behind them one or two barges equal in carrying capacity to themselves. In this way three ships' cargoes of ore are transported a thousand miles by a score of men, a dozen on the steamer and three or four on each of the barges. The barges themselves are rigged as ships, and if necessary can shift for themselves by means of sails attached to their stubby masts. But these are used only on special and unusual occasions, as in case of accidental parting of the hawsers during a storm.

The problem of loading the ships at the ore wharves is a simple one as compared with the equally important one of transferring the ore from the hold to trains of cars in waiting at the eastern end of the water route. For four handlings of the ore are necessary before it is finally deposited in the furnaces in the east. The first of these is from the mine to cars; the second from the cars to the boats; the third from the boats to cars; and the fourth from the cars to the blast furnaces.

For many years about the only hand work done in any of these processes was that of transferring from the boats to the ore-trains, and even here "automatic unloaders" are now rapidly supplanting the tedious hand method. By the older methods a travelling crane, or swinging derrick, dropped a bucket into the hold of the ore-vessel, where workmen shovelled it full of the red ore. It was then lifted out by machinery and the contents dumped into cars in much the same manner as that of the steam shovel in the mines. Recently, however, a machine has been perfected which scoops up the ore from the ship's hold and transfers it to the cars without the aid of shovellers. The only human aid given this gigantic machine is to guide it by means of controlling levers—to furnish brains for it, in short—the "muscle" being furnished by steam power. The great arm of this automatic unloader, resembling the sweep of the old-fashioned well in principle, moves up and down, burying the jaws of the shovel into the ore in the hold, and pulling them out again filled with ore, with monotonous regularity, quickly emptying the vessel under the guidance of half a dozen men, and performing the labor of hundreds.

Thus the last field of activity for the laborer and his shovel, in the iron-ore industry, has been usurped by mechanical devices. From the time the ore is taken from the mine until it appears as molten metal from the furnaces, it is not touched except by mechanisms driven by steam, compressed air, or electricity. And yet, so rapid is the growth of the iron and steel industry that there is almost always a demand for more workmen.

For this reason, and perhaps because of the "American spirit" among workmen, innovations in the way of labor-saving machinery are not resisted among the mine laborers. The American workman seldom resists or attacks machinery on the ground that it "throws him out of a job," as does his English cousin. It would be unjust to attribute this attitude to superior acumen on the part of the American workman, and it is probably a difference in conditions and surroundings that accounts for the diametrically opposite views held by laborers on the two sides of the Atlantic. But after all, results must speak for themselves, and the advantage all lies in favor of the progressive attitude of the western laborer, if we may judge by the relative social status and financial standing of European and American workmen.

THE CONVERSION OF IRON ORE INTO IRON AND STEEL

Since steel is a compound substance composed essentially of two elementary substances in varying proportions, it appears that the name "steel," like wood, refers to a class of which there are several varieties. This, of course, is the case, but for the moment we may consider steel as a single substance composed chiefly of iron and containing a certain percentage of carbon. In this respect it resembles cast iron, steel having a smaller amount of carbon. Wrought iron, on the other hand, contains no carbon at all, or at least only a trace of it. But whatever the ultimate destiny of iron ore—whether it is to become aristocratic manganese steel, or plebeian cast iron—it must first pass through certain processes before being "converted."

To extract the pure iron from the iron ore it is necessary to heat the ore in a furnace containing a certain quantity of coal, coke, or charcoal, and limestone. The furnaces used in this process are known as blast-furnaces, and in these about one ton of iron is extracted for every two tons of Lake Superior ore, one and a quarter tons of coke, and half a ton of limestone used. These quantities are by no means constant, of course, but they may be taken as representing roughly the relative amounts of material that must be fed into the furnaces.

Like everything else in the world of iron and steel, these blast-furnaces have undergone revolutionary improvements during the past quarter of a century. From being most dangerous and destructive structures causing frightful loss of life and producing only about one ton of iron a day for every man working about them, as formerly, they have now become relatively harmless monsters, capable of turning out six times that quantity of ore for each man employed.

The older blast-furnace was a huge, chimney-like structure, perhaps a hundred feet high, into which the ore, coal, and limestone were poured. Most of the work about these furnaces was done by manual labor; or at least manual labor was an active assistant to the machinery used in manipulating the furnaces. The top of the furnace was closed in by a great movable lid, or "bell," and the material for charging it was hauled up the sides by elevators and dumped in at the top. About the top of the furnace was constructed a staging upon which the workmen stood, an elevator shaft connecting the staging with the ground. The ore and other materials were brought to the foot of the shaft on cars from which it was shovelled into peculiarly designed wheelbarrows, trundled to the elevator, and hauled to the top.

In order to dump the wheelbarrow loads into the furnaces it was necessary to raise the bell. This was always dangerous, and frequently resulted in the suffocation or injury of the workmen on the staging. For when the bell was raised there was an escape of poisonous gases, which might flare out in a sheet of flame, with the possibility of burning or suffocating the workmen. The fumes from these gases, if inhaled in small quantities, might simply cause coughing, hiccoughing, or dizziness; but when inhaled in large quantities they struck down a man like the fumes of chloroform, suffocating him in a few seconds if he was not removed at once into a purer atmosphere. Indeed, the likelihood of this was so great that at many of these furnaces a special workman was detailed to take the position on the staging, well out of range of the gas, his sole duty being to rescue any of the men who might be overcome, and hurry them as quickly as possible down the elevator shaft into the pure atmosphere below. It was not an uncommon thing in the neighborhood of these older furnaces to see stretched about on the ground at the base several workmen in various stages of suffocation. Fortunately, by use of precautionary measures, fatal accidents were rather unusual, the men being overcome only temporarily, and usually recovering quickly and returning to work.

But the poisonous gas coming from the top of the furnace was not the only, nor the worst, danger constantly menacing the men on the staging. Their greatest dread was the possibility of explosions occurring in the furnace, which might hurl the bell into the air and deluge the upper structure with molten metal. Against this possibility there was no safeguard in the older furnaces, explosions occurring without warning and frequently with terrible effects. But fortunately these older types of furnaces are being rapidly replaced by the newer forms in which the danger to life, at least from gas and explosions, is minimized. And even in the older furnaces, improvements in the structure of the bell and in methods of filling have greatly lessened the dangers.

In the modern type of blast-furnace the work at the top formerly performed by men on the staging is accomplished entirely by machinery. The general appearance of these furnaces is that of huge iron pipes or kettles mounted on several iron legs. The outer structure, or shaft, is constructed of plate iron, but this is lined with fire brick of considerable thickness, and may have a water jacket interposed between these bricks and the shaft. About this large kettle are smaller kettles of somewhat similar shape having pipes leading from their tops to the larger structure. These smaller kettles are the "stoves" used in producing the hot air for the furnace.

The working capacity of some of these furnaces is in the neighborhood of a thousand tons of iron a day, although the average furnace produces only about half that quantity. The powerful machinery used for charging these monster caldrons hauls the ore and other charging materials to the top and dumps it in car-load lots.

In the older methods of manufacturing steel, the contents of the blast-furnaces were first drawn off into molds and allowed to cool into what is known as pig-iron. It was then necessary to re-heat this iron and treat it by the various methods for producing the kind of steel desired. By the newer methods, however, time and money are saved by converting the liquid iron from the blast-furnace directly into steel without going through the transitional stage of cooling it into pigs. Pigs of iron are still made in enormous quantities, to be sure, but mostly for shipment to distant places or for stores as stock material. For statistical purposes, however, the entire product of the blast-furnace, whether liquid or solid, is known as "pig iron."

The older method of removing the iron from the blast furnaces was by tapping at the opening near the bottom, the stream of liquid iron being allowed to flow into a connected series of sand molds, each mold being about three feet long by three or four inches wide. The bottom of these molds was flat but as the metal cooled in them the upper surface became round in shape, assuming a fanciful resemblance to a pig's back. In this molding a great amount of time was wasted in the slow process of cooling, and a large expenditure of energy wasted in this handling and rehandling of the metal.

In modern smelting works, however, pigs are no longer cast in sand molds, the molten metal from the furnace being discharged directly into iron molds attached to an endless chain. These molds are long, narrow, and shallow, having the general shape of sand molds. Each mold as it passes beneath the opening in the furnace remains just long enough to receive the requisite amount of metal to fill it, and then moves on to a point where it is either sprayed with water, or cooled by actually passing through a tank of water, emerging from this bath with the metal sufficiently solidified so that it may be dropped into a waiting car at the turning point of the endless chain. In this manner the charge from the blast-furnace may be drawn, cooled, and converted into pigs, loaded into cars, and hauled away without extra handlings or loss of time, the whole process occupying practically no more time than the initial step of tapping by the older method.

Where the contents of the blast-furnace are to be converted into steel at once, the molten metal is run off into movable tanks which carry it directly to the steel furnaces. These tanks, holding perhaps twenty tons of metal, are made of thick iron lined with fire brick, and arranged on low, flat cars designed specially for the purpose. These tanks are run under the spout of the furnace, filled with molten metal, and drawn to the steel works, possibly five miles away. As a rule, the distance is much less, but as far as the condition of the metal is concerned distance seems to make little difference, as even at the extreme distance there is no apparent cooling of the seething mass. The intense heat given off by these trains necessitates specially constructed cars, tracks, bridges, and crossings.

The destination of this train load of iron pots is the "mixer"—a great 200-ton kettle in which the products from the various furnaces are mixed and rendered uniform in quality. On the arrival of the train at the mixer, Titanic machinery seizes the twenty-ton pots and dumps their contents bodily into the glowing pool in the great crucible. Like the filling process, this operation occupies only a few minutes.

From the mixer the metal is poured out into ladles and transferred immediately to the "converter"—the important development of Sir Henry Bessemer's discovery that has made possible the modern steel industry. This converter resembles in shape some of the old mortars used in the American Civil War—barrel-shaped structures suspended vertically by trunnions at the middle and having an opening at the top. Into this opening at the top the metal from the mixer is poured and when the converter has been sufficiently charged a blast of cooled air is blown in at the bottom through the molten metal. This blast emerges at the top as a long roaring flame, of a red color at first but gradually changing into white, and then faint blue. These changes in color are indicative of the changes that are taking place in the metal, and the appearance of a certain shade of color indicates that the conversion into steel is complete, and that it is time for shutting off the blast of air. Any mistake in this matter—even the variation of thirty seconds' time—means a loss of thousands of dollars in the quality of steel produced. The man whose duty it is to determine this important point, therefore, holds an exceptionally delicate and responsible position, and receives pay accordingly.

In deciding the exact moment when the blast shall be turned off, this workman is guided entirely by the sense of sight. Mounted on a platform commanding the best possible view of the mouth of the converter and wearing green glass goggles of special construction, this man watches the change of color in the flame until a certain shade is reached—a shade that to the ordinary untrained observer does not differ in appearance from that of a moment before—when he gives the signal to shut off the blast. When this signal is given the contents of the converter is no longer common-place cast iron, but steel, ready to be molded into rails, boilers, or a thousand and one other useful things.

The contents of the converter may now be drawn off as liquid steel into molds of any desired shape and size, and when cooled will be ready for shipment. But in the great steel factories the metal is not ordinarily allowed to cool completely before being sent to the rolling mills, being drawn off into molds placed along the surface of small, flat cars. These molds are rectangular, ordinarily four or five feet high by less than two feet in diameter. The metal is poured into openings in the top of each mold, and allowed to cool, solidify, and to contract enough to permit the outer casings of the molds to be pulled off by machinery, leaving the glowing "ingots" of steel ready for molding by machinery in the mills.

The process just described is the one by which "Bessemer steel" is made. There is another important process in use, the "open hearth" method, which differs considerably from this; but before considering this process something more should be said of the man whose discoveries made possible the modern steel industry.

SIR HENRY BESSEMER

In the history of the progress of science and invention some one great name is usually pre-eminently associated with epoch-marking advances, although there may be a cluster of important but minor associates. This is true in the history of the modern steel industry, and the central name here is that of Sir Henry Bessemer.

Bessemer was born at Charlton, England, on Jan. 19, 1813. Always of an inventive turn of mind, his attention was first directed to improving the methods then in use for the manufacture of steel, while experimenting with the manufacture of guns. After several years of experimenting in his little iron works near London, he reached some definite results which he announced to the British Association in 1856. In this paper he described a process of converting cast iron into steel by removing the excess of carbon in the molten metal by a blast of air driven through it. This paper, in short, described the general principles still employed in the Bessemer process of manufacturing steel. And although the first simple process described by Bessemer has been modified and supplemented in recent years, it was in this paper that the process which placed steel upon the market as a comparatively cheap, and infinitely superior, substitute for ordinary iron, was first disclosed.

This famous paper before the British Association aroused great interest among the English ironmasters, and applications for licenses to use the new process were made at once by several firms. But the success attained by these firms was anything but satisfactory, although Bessemer himself was soon able to manufacture an entirely satisfactory product. The disappointed ironmasters, therefore, returned to the earlier processes, the inventor himself being about the only practical ironmaster who persisted in using it.

Recognizing the defects in his process, Bessemer set about overcoming them, and at the end of two years he had so succeeded in perfecting his methods that his product, equal in every respect to that of the older process, could be manufactured at a great saving of time and money. But the ironmasters were now skeptical, and refused to be again inveigled into applying for licenses. Bessemer, therefore, with the aid of friends, erected extensive steel works of his own at Sheffield, and began manufacturing steel in open competition with the other steel operators. The price at which he was able to sell his product and realize a profit was so much below the actual cost of manufacture by the older process, that there was soon consternation in the ranks of his rivals. For when it became known that the firm of Henry Bessemer & Co. was selling steel at a price something like one hundred dollars a ton less than the ordinary market price, there was but one thing left for the ironmasters to do —surrender, and apply for licenses to be allowed to use the new process.

By this means, and through the profits of his own establishment, Bessemer eventually amassed a well-earned fortune. Moreover, he was honored in due course by a fellowship in the Royal Society, and knighted by his government.

One other name is usually associated with that of Bessemer in the practical development of the inventor's original idea. That is the name of Robert Mushet, and the "Bessemer-Mushet" process is still in use. Mushet's improvement over Bessemer's original process was that of adding a certain quantity of *spiegeleisen*, or iron containing manganese, which, for some reason not well understood, simplifies the process of steel making. Mushet, therefore, must be considered as the discoverer of a useful, though not an absolutely essential, accessory to the Bessemer process.

OPEN-HEARTH METHOD

In the open-hearth method the metal from the blast-furnaces is not sent to the converter, but is poured into oven-like structures built of fire brick, and in these heated to a terrific temperature. This heat has the same effect upon the metal as the blast of air in the Bessemer converter, and this open-hearth process has become very popular for manufacturing certain kinds of steel. While in the method of application this process differs greatly from that of Bessemer, it differs largely in the fact that the oxygen necessary to burn off the carbonic oxide, silicon, etc., is made to play over the molten mass instead of passing through it.

It has been noted that the old type of blast-furnace gave off great quantities of combustible gases which became waste products. Even gases containing something like 20 or 25 per cent. of carbonic acid may be highly inflammable, and thus an enormous quantity of valuable fuel was constantly wasted. In some furnaces, to be sure, they were put to practical use for heating the blast, but as the quantities given off were greatly in excess of the amount necessary for this purpose, there was a constant loss even with such furnaces.

Quite recently it has been found that the gases can be used directly in gas engines, developing three or four times as much energy in this way as if they were used as fuel under ordinary steam boilers. These engines are now used for operating the rolling-mill machinery, and the machinery of shops adjoining the furnaces, which, however, must not be situated at any very great distances from the furnaces. This accounts partly for the grouping together of blast-furnaces, rolling mills, and machine shops, the economical feature of this arrangement being so great that segregated establishments find it next to impossible to compete in the open market with such "communities" under the conditions prevailing in the steel industry.

ALLOY STEELS

The introduction of Krupp steel, or nickel, for armor plates, a few years ago, called attention in a popular way to the fact that for certain purposes pure steel—that is, iron plus a certain quantity of carbon—was not as useful as an alloy of steel with some other metal. An alloy was a great improvement over ordinary steel or iron plates used in warfare; but in the more peaceful pursuits, as well as in warfare, certain alloyed steels, such as chrome steel, tungsten steel, and manganese steel play a very important part.

Chrome steel, for example, in the form of projectiles, is the most dreaded enemy of nickel-steel armor plates, because of the hardness and elasticity of armor-piercing projectiles made of it. Such a steel contains about two per cent. of chromium with about one or two per cent. of carbon, which when suddenly cooled is extremely hard and tough. This kind of steel and manganese steel are the best guards against the burglar and safe-blower, as they resist even very highly tempered and hardened drills. As this steel is relatively cheap to manufacture, it is frequently used in the construction of safes and burglar-proof gratings. For this purpose, however, it is sometimes combined in alternate layers with soft wrought iron, the steel resisting the point of the drill, while the iron furnishes the necessary elasticity to resist the blows of the sledge. The bars used in modern jails and prisons are often made in a similar manner of alternate sheaths of iron and chrome steel. Against the time-honored "hack-saw," the bugbear of prison officials for generations, such bars an inch and a quarter in diameter offer an almost insurmountable obstacle; and they are equally effective against a heavy sledge hammer.

At least one case is recorded in which the use of these "composite" bars resulted in a disastrous fire in a prison. A small blaze having started in the basement of this prison, attempts to reach it with a stream of water were defeated by the bars of the steel gratings at the windows, which would not admit the nozzle of the hose. A corps of men armed with hack-saws, crow-bars, and sledges attacked this grating, which, if made of ordinary steel, could have been readily broken. But against these composite bars they produced no appreciable effect. Meanwhile the fire gained rapidly, threatening the building and its eight hundred inmates, and was only checked after holes had been made through fire-proof floors and ceilings for admitting the nozzle.

Manganese steel is peculiar in becoming ductile by sudden cooling, and brittle on cooling slowly—precisely the reverse of ordinary steel. It contains about

1.50 per cent. of carbon, and about 12 per cent. of manganese. If a small quantity of manganese, that is, 1 or 2 per cent., is used the steel is very brittle, and becomes more so as greater quantities of the manganese are used, up to about 5 per cent. From that point, however, it becomes more ductile as the quantity of manganese is increased, until at about 12 per cent. it reaches an ideal state. When used for safes and money vaults this steel has one great advantage over chrome steel—it is not affected by heat. By using a blow-pipe and heating a limited area of steel, the burglar is able to "draw the temper" of ordinary steel to a sufficient depth so that he can drill a hole to admit a charge of dynamite; but manganese steel retains its temper under the blow-pipe no matter how long it may be applied. Against attacks of the sledge, however, it is probably inferior to chrome steel.

Like manganese steel, tungsten steel retains its temper even when heated to high temperatures. For this reason it is used frequently in making tools for metal-lathe work where thick slices of iron are to be cut, as even at red heat such a tool continues to cut off metal chips as readily as when kept at a lower temperature. This steel contains from 6 to 10 per cent. of tungsten, a metallic element with which we have previously made acquaintance in our studies of the incandescent lamp.

XIV

SOME RECENT TRIUMPHS OF APPLIED SCIENCE

NOT long ago a little company of men met in a lecture hall of Columbia University to discuss certain questions in applied science. It was a small gathering, and its proceedings were so unspectacular as to be esteemed worth only a few lines of newspaper space. The very name—"Society of Electro-Chemistry"—seemed to mark it as having to do with things that are caviare to the general. The name seems to smack of fumes of the laboratory, far removed from the interests of the man in the street. Yet Professor Chandler said in his address of welcome to the members of the society, that though theirs was the very youngest of scientific organizations, he could confidently predict for it a future position outranking that of all its sister societies; and his prediction was based on the belief that electro-chemistry is destined to revolutionize vast and important departments of modern industry. A majority of the heat-using methods of mechanics will owe their future development to the new science.

In a word, then, despite its repellant name, the society in question has to do with affairs that are of the utmost importance to the man in the street. Though its members may sometimes deal in occult formulas and abstruse calculations, yet the final goal of their studies has to do not with abstractions but with practicalities,—with the saving of fuel, the smelting of metals, the manufacture of commodities. But theory in the main must precede practice—the child creeps before it walks. "The later developments of industrial chemistry," says Sir William Ramsey, "owe their success entirely to the growth of chemical theory; and it is obvious," he adds significantly, "that that nation which possesses the most competent chemists, theoretical and practical, is destined to succeed in the competition with other nations for commercial supremacy and all its concomitant advantages."

Fortunately this interdependence of science and industry is not a mere matter of prophecy—for the future tense is never quite so satisfying as the present. Vastly important changes have already been accomplished; old industries have been revolutionized, and new industries created. The commercial world of to-day owes vast debts to the new science. Professor Chandler outlined the character of one or two of these in the address just referred to. He cited in some detail, for example, the difference between old methods and new in such an industry as the manufacture of caustic soda. He painted a vivid word picture of the distressing conditions under which soda was produced in the old-time factories. Salt and sulphuric acid were combined to produce sulphate of soda, which was mixed with lime and coal and heated in a reverberatory furnace. Each phase of the process was laborious. The workmen operating the furnaces sweltered all day long in an almost unbearable atmosphere—stripped to the waist, dripping with perspiration, sometimes overcome with heat. Their task was one of the most trying to which a man could be subjected.

But to-day, in such establishments as the soda manufactories at Niagara Falls, all this is changed. A salt solution circulates continuously in retorts where it can be acted upon by electricity supplied from dynamos operated by the waters of the Niagara River. The workmen, comfortably dressed and moving about in a normal temperature, have really nothing to do but refill the retorts now and then and remove the finished product. "It almost seems," Professor Chandler added with a smile, "as if workmen ought to be glad to pay for the privilege of participating in so pleasant an occupation. At all events it is, in all seriousness, a pleasure for the visitor who knows nothing of old practices to witness this triumph of a modern scientific method."

Even more interesting, said Professor Chandler, are the processes employed in the modern method of producing the metal aluminum by the electrolytic process. The process is based on the discovery made by Mr. Charles M. Hall while he was a student working in a college laboratory, that the mineral cryolite will absorb alumina to the extent of twenty-five per cent. of its bulk, as a sponge absorbs water. The solution of this compound is then acted on by electricity, and the aluminum is deposited as pure metal. A curiously interesting practical detail of the process is based on the fact that pulverized coke remains perfectly dry and rises to the surface when stirred into a crucible containing the hot alumina solution: moreover, it rises to the surface and remains there as a shield to protect the workmen against the heat of the solution. It serves yet another purpose, as the powdered alumina may be sifted upon it and left there to dry before being stirred into the crucible. A most ingenious yet simple device tells the workman when any particular crucible is in need of replenishing. A small, ordinary, incandescent electric-light bulb is placed in circuit between the poles that convey the electric current through the alumina solution. So long as the crucible contains alumina, the bulb does not glow, because twenty volts of electricity are required to make it incandescent, whereas seven volts pass through the solution. But so soon as the alumina becomes exhausted, resistance to the current rises in the cryolite solution and, as it were, dams back the electric current until it overflows into the wire at sufficient pressure to start the signal lamp. Then it is necessary merely for a workman to stir into the solution the dry alumina resting on the surface, along with the coke that supports it. This, of course, reestablishes the electrolytic process; the lamp goes out and the coke, unaffected by its bath, rises to the surface to support a fresh supply of alumina.

Such a process as this, contrasted with the usual methods of smelting metals in fiercely heated furnaces, seems altogether wonderful. Here a pure metal is extracted from the clayey earth of which it formed a part, without being melted or subjected to any of the familiar processes of the picturesque, but costly, laborious, and even dangerous, blast-furnaces. There is no glare and roar of fires; there are no showers of sparks; there is no gush of fiery streams of molten metal. A silent and invisible electric current, generated by the fall of distant waters, does the work more expeditiously, more efficiently, and more cheaply than it could be done by any other method as yet discovered.

Fully to appreciate the importance of the method just outlined, we must reflect that aluminum is a metal combining in some measure the properties of silver, copper, and iron. It rivals copper as a conductor of electricity; like silver it is white in color and little subject to tarnishing; like iron it has great hardness and tensile strength. True, it does not fully compete with the more familiar metals in their respective fields; but it combines many valuable qualities in fair degree; and it has an added property of extreme lightness that is all its own. Add to this the fact that aluminum is extremely abundant everywhere in nature—it is a constituent of nearly all soils and is computed to form about the twelfth part of the entire crust of the earth —whereas the other valuable metals are relatively rare, and it will appear that aluminum must be destined to play an important part in the mechanics of the future. There is every indication that the iron beds will begin to give out at no immeasurably distant day; but the supply of aluminum is absolutely inexhaustible. Until now there has been no means known of extracting it cheaply from the clay of which it forms so important a constituent. But at last electro-chemistry has solved the problem; and aluminum is sure to take an important place among the industrial metals, even should it fall short of the preeminent position as "the metal of the future" that was once prematurely predicted for it.

NITROGEN FROM THE AIR

There is a curious suggestiveness about this finding of aluminum at our very door, so to speak, some scores of centuries after the relatively rare and inaccessible metals had been known and utilized by man. But there is another yet more striking instance of an abundant element which man needed, but knew not how to obtain until the science of our own day solved the problem of making it available. This is the case of the nitrogen of the air. As every one knows, this gas forms more than three-fourths of the bulk of the atmosphere. But, unlike the other chief constituent, oxygen, it is not directly available for the use of plants and animals. Yet nitrogen is an absolutely essential constituent of the tissues of every living organism, vegetable and animal. Any living thing from which it is withheld must die of starvation, though every other constituent of food be supplied without stint; and the fact that the starving organism is bathed perpetually in an inexhaustible sea of atmosphere chiefly composed of nitrogen would not abate by one jot the certainty of its doom.

To be made available as food for plants (and thus indirectly as food for animals) nitrogen must be combined with some other element, to form a soluble salt.

But unfortunately the atoms of nitrogen are very little prone to enter into such combinations; under all ordinary conditions they prefer a celibate existence. In every thunder-storm, however, a certain quantity of nitrogen is, through the agency of lightning, made to combine with the hydrogen of dissociated water-vapor, to form ammonia; and this ammonia, washed to the earth dissolved in rain drops, will in due course combine with constituents of the soil and become available as plant food. Once made captive in this manner, the nitrogen atom may pass through many changes and vicissitudes before it is again freed and returned to the atmosphere. It may, for example, pass from the tissues of a plant to the tissues of a herbivorous animal and thence to help make up the substance of a carnivorous animal. As animal excreta or as residue of decaying flesh it may return to the soil, to form the chief constituent of a guano bed, or of a nitrate bed,—in which latter case it has combined with lime or sodium to form a rocky stratum of the earth's crust that may not be disturbed for untold ages.

A moment's reflection on the conditions that govern vegetable and animal life in a state of nature will make it clear that a soil once supplied with soluble nitrates is likely to be replenished almost perpetually through the decay of vegetation. But it is equally clear that when the same soil is tilled by man, the balance of nature is likely to be at once disturbed. Every pound of grain or of meat shipped to a distant market removes a portion of nitrogen; and unless the deficit is artificially supplied, the soil becomes presently impoverished.

But an artificial supply of nitrogen is not easily secured—though something like twenty-five million tons of pure nitrogen are weighing down impartially upon every square mile of the earth's surface. In the midst of this tantalizing sea of plenty, the farmer has been obliged to take his choice between seeing his land become yearly more and more sterile and sending to far-off nitrate beds for material to take the place of that removed by his successive crops. The most important of the nitrate beds are situated in Chili, and have been in operation since the year 1830. The draft upon these beds has increased enormously in recent years, with the increasing needs of the world's population. In the year 1870, for example, only 150,000 tons of nitrate were shipped from the Chili beds; but in 1890 the annual output had grown to 800,000 tons; and it now exceeds a million and a half. Conservative estimates predict that at the present rate of increased output the entire supply will be exhausted in less than twenty years. And for some years back scientists and economists have been asking themselves, What then?

But now electro-chemistry has found an answer—even while the alarmists were predicting dire disaster. Means have been found to extract the nitrogen from the atmosphere, in a form available as plant food, and at a cost that enables the new synthetic product to compete in the market with the Chili nitrate. So all danger of a nitrogen famine is now at an end,—and applied science has placed to its credit another triumph, second to none, perhaps, among all its conquests. The author of this truly remarkable feat is a Swedish scientist, Christian Birkeland by name, Professor of Physics in the University of Christiania. His experiments were begun only about the year 1903, and the practical machinery for commercializing the results—in which enterprise Professor Birkeland has had the co-operation of a practical engineer, Mr. S. Eyde—is still in a sense in the experimental stage,—albeit a large factory was put in successful operation in 1905 at Notodden, Norway.

Professor Birkeland has thus accomplished what many investigators in various parts of the world have been striving after for years. The significance of his accomplishment consists in the fact that he has demonstrated the possibility of making nitrogen combine with oxygen in large quantities and at a relatively low expense. The mere fact of the combination, as a laboratory possibility, had been demonstrated in an elder generation by Cavendish, and more recently by such workers as Sir William Crookes, and Lord Rayleigh in England and Professors W. Mutjmaan and H. Hofer in Germany. Moreover, the experiments of Messrs. Bradley and Lovejoy, conducted on a commercial scale at Niagara Falls, had seemed to give promise of a complete solution of the problem; had, indeed, produced a nitrogen compound from the air in commercial quantity, but not, unfortunately, at a cost that made competition with the Chili nitrate possible. Equally unsuccessful in solving this important part of the problem had been the experiments, conducted on a large scale, of Professors Kowalski and Moscicki, at Freiburg.

All these experimenters had adopted the same agent as the means of, so to say, forcing the transformation —namely, electricity. The American investigators employed a current of ten thousand volts; the German workers carried the current to fifty thousand volts. The flame of the electric arc thus produced ignited the nitrogen with which it came in contact readily enough; but the difficulty was that it came in contact with so little. Despite ingenious arrangements of multiple poles, the burning-surface of the multiple arc remained so small in proportion to the expenditure of energy that the cost of the operation far exceeded the commercial value of the product. Such, at least, must be the inference from the fact that the establishments in question did not attain commercial success.

The peculiarity of Professor Birkeland's method is based upon the curious fact that when the electric arc is made to pass through a magnetic field, its line of flame spreads out into a large disk—"like a flaming sun." The sheet of flame thus produced represents no greater expenditure of energy than the lightning flash of light that the same current would produce outside the magnetic field; but it obviously adds enormously to the arc-light surface that comes in contact with the air, and hence in like proportion to the amount of nitrogen that will be ignited. In point of fact, this burning of nitrogen takes place so rapidly in laboratory experiments as to vitiate the air of the room very quickly. In the commercial operation, with powerful electro-magnets and a current of five thousand volts, operating, of course, in closed chambers, the ratio between energy expended and result achieved is highly satisfactory from a business standpoint, and will doubtless become still more so as the apparatus is further perfected.

To the casual reader, unaccustomed to chemical methods, there may seem a puzzle in the explanation just outlined. He may be disposed to say, "You speak of the nitrogen as being ignited and burned; but if it is burned and thus consumed, how can it be of service?" Such a thought is natural enough to one who thinks of burning as applied to ordinary fuel, which seems to disappear when it is burned. But, of course, even the tyro in chemistry knows that the fuel has not really disappeared except in a very crude visual sense; it has merely changed its form. In the main its solid substance has become gaseous, but every atom of it is still just as real, if not quite so tangible, as before; and the chemist could, under proper conditions, collect and weigh and measure the transformed gases, and even retransform them into solids.

In the case of the atmospheric nitrogen, as in the case of ordinary fuel, a burning "consists essentially in the union of nitrogen atoms with atoms of oxygen." The province of the electric current is to produce the high temperature at which alone such union will take place. The portion of nitrogen that has been thus "burned" is still gaseous, but is no longer in the state of pure nitrogen; its atoms are united with oxygen atoms to form nitrous oxide gas. This gas, mixed with the atmosphere in which it has been generated, may now be passed through a reservoir of water, and the new gas combines with a portion of water to form nitric acid, each molecule of which is a compound of one atom of hydrogen, one atom of nitrogen, and three atoms of oxygen; and nitric acid, as everyone knows, is a very active substance, as marked in its eagerness to unite with other substances as pure nitrogen is in its aloofness.

In the commercial nitrogen-plant at Notodden, the transformed nitrogen compound is brought into contact with a solution of milk of lime, with the resulting formation of nitrate of lime (calcium nitrate), a substance identical in composition—except that it is of greater purity—with the product of the nitrate beds of Chili. Stored in closed cans as a milky fluid, the transformed atmosphere is now ready for the market. A certain amount of it will be used in other manufactories for the production of various nitrogenous chemicals; but the bulk of it will be shipped to agricultural districts to be spread over the soil as fertilizer, and in due course to be absorbed into the tissues of plants to form the food of animals and man.

ANOTHER METHOD OF NITROGEN FIXATION

Just at the time when the Scandinavian experimenters were solving the problem of securing nitrogen from the air, other experimenters in Italy, operating along totally different lines, reached the same important result. The process employed by these investigators is known as the Frank and Caro process, and it bids fair to rival the Norwegian method as a commercial enterprise.

The process is described as follows by an engineering correspondent of the London *Times* in the Engineering Supplement of that periodical for January 22, 1908:

"This process is based upon the absorption of nitrogen by calcium carbide, when this gas, in the pure form, is passed over the carbide heated to a temperature of 1,100 degrees centigrade in retorts of special form and design. The calcium carbide required as raw material for the cyanamide manufacture is produced in the usual manner by heating lime and coke to a temperature of 2,500 degrees centigrade in electric furnaces of the resistance type.

"The European patent rights of the Frank and Caro process have been purchased by the Societa Generale per la Cianamide of Rome, and the various subsidiary companies promoting the manufacture in Italy, France, Switzerland, Norway, and elsewhere, are working under arrangement with the parent company as regards sharing of profits.

"The first large installation of a plant for carrying out this process was erected at Piano d'Orta, in Central Italy, and was put into operation in December, 1905. The power for this factory is developed by an independent company, and is obtained by taking water from the river Pescara and leading it to a point above the generating station at Tramonti. A head of 90 feet, equivalent to 8,400 horse-power, is here made available for the industries of the district. The power of the cyanamide factory is transmitted a distance of 6¼ miles at 6,000 volts. An aluminum and chemical works are also dependent upon the same power station.

"The Piano d'Orta works contains six furnaces for the manufacture of cyanamide, each furnace containing five retorts for absorption of the nitrogen by the carbide. A retort is capable of working off three charges of 100 kilograms (220 pounds) of carbide per day of 24 hours, the weight of the charge increasing to 125 kilograms by the nitrogen absorbed. The present carbide consumption of the Piano d'Orta factory is, therefore, at the rate of about 3,000 tons per annum, and the output of calcium cyanamide is about 3,750 tons per annum. The company controlling the manufacture at Piano d'Orta is named the *Societa Italiana per la Fabbricazione di Prodotti Azotati.* Extensions of the factory at this place to a capacity of 10,000 tons per annum are already in progress. Another company is also planning the erection of similar works at Fiume and at Sebenico, on the eastern borders of the Adriatic Sea. The additional electric power required will be obtained by carrying out the second portion of the power development scheme on the river Pescara. A fall of 235 feet, equivalent to 22,000 horse-power, is available at the new power station, which is being erected at Piano d'Orta."

After stating that companies to operate the Frank and Caro process have been organized in France, in Switzerland, in Germany, in England, and in America, —the last-named plant being at Muscle Shoals, Tennessee River, in Northern Alabama—the writer continues:

"These facts prove that the manufacture of the new nitrogenous manure will soon be carried on in all the more important countries on both sides of the Atlantic. If the financial results come up to the promoter's expectations the industry in five years' time will have become one of considerable magnitude.

"A modification of the original process of some importance has been suggested by Polzeniusz. This chemist has found that the addition of fluorspar (CaF_2) to the carbide reduces the temperature required for the absorption process by 400 degrees centigrade, while it also produces a less deliquescent finished material.

"As regards cost of manufacture, no very reliable figures are yet available, but the companies promoting the new manufacture are regulating their sale prices by those of the two rival artificial manures—ammonium sulphate and nitrate of soda. Calcium cyanamide is now being sold in Germany at 1s. to 1s. 6d. (25 to 37 cents) per unit of combined nitrogen cheaper than ammonium sulphate, and 3s. to 3s. 6d. (75 to 87 cents) per unit cheaper than nitrate of soda. Whether the manufacture will prove remunerative at this price of about £10 10s. ($102.50) per ton remains to be seen. It is evident that, as the raw material of the cyanamide manufacture (calcium carbide) costs at least £8 ($40) per ton to produce under the most favorable conditions, the margin of profit will not be large, and that very efficient management will be required to earn fair dividends on the capital sunk in the new industry.

"It must be noted, however, that the processes are new and are doubtless capable of improvement as experience is gained in working them; while, on the other hand, the competition of the two rival artificial manures is likely to diminish as the years pass on.

"The new industry is, therefore, likely to be a permanent addition to the list of electro-metallurgical processes. But for the present its success can only be expected in centres of very cheap water-power, as, for instance, in those localities where the electric horse-power year can be generated and transmitted to the cyanamide works at an inclusive cost of £2 ($10) or under."

ELECTRICAL ENERGY AND HIGH TEMPERATURES

It will be observed that the active instrumentality by which the industrial feats thus far outlined have been accomplished, is that weird conveyer of energy known as electricity. In the case of the aluminum manufacture, electricity operated according to the strange process of electrolysis, in virtue of which certain atoms of matter move to one pole of a battery while other atoms move to the opposite pole, thus effecting a separation—the result being, in the case in question, the deposit of pure aluminum at the negative pole. In the case of the nitrogen factories, however, the manner of operation of the electric current is quite different. Electricity, as such, is not really concerned in the matter; the efficiency of the current depends solely upon the production of heat. For example, any other agency that brought the atmosphere to a corresponding temperature would be equally efficacious in igniting the nitrogen. But in actual practice, for this particular purpose, no other known means of producing high temperatures could at all compete with the electric arc.

There are numerous other operations involving the employment of high temperatures in which electricity is equally preeminent. It is feasible with the electric arc to attain a temperature of about 3,600 degrees centigrade—and even this might be exceeded were it not that carbon, of which the electrodes are composed, volatilizes at that temperature. Meantime, the highest attainable temperature with ordinary fuels in the blast furnace is only about 1,800 degrees; and the oxy-hydrogen flame is only about two hundred degrees higher. A mixture of oxygen and acetylene, however, burns at a temperature almost equaling that of the electric arc; and this flame, manipulated with the aid of a blowpipe, offers a useful means of applying a high temperature locally, for such processes as the welding of metals. The very highest temperatures yet reached in laboratory or workshop, however, are due to the use of explosive mixtures. Thus a mixture of the metal aluminum granulated, and oxide of iron, when ignited by a fulminating powder, readjusts its atoms to form oxide of aluminum and pure iron, and does this with such fervor that a temperature of about three thousand degrees is reached, the resulting iron being not merely melted but brought almost to the boiling point. Practical advantage is taken of this reaction for the repair of broken implements of iron or steel, the making of continuous rails for trolleys, and the like.

This reaction of aluminum and iron does not, to be sure, give a higher temperature than the electric arc; but this culminating feat has been achieved, in laboratory experiments, through the explosion of cordite in closed steel chambers; the experimenters being the Englishmen Sir Andrew Noble and Sir F. Abel. It is difficult to estimate accurately the degree of heat and pressure attained in these experiments; but it is believed that the temperature approximated 5,000 degrees centigrade, while the pressure represented the almost inconceivable push of ninety tons to the square inch.

It may be of interest to explain that cordite is a form of smokeless powder composed of gun cotton, nitroglycerine, and mineral jelly. No doubt the extreme heat produced by its explosion is associated with the suddenness of the reaction; corresponding to the efficiency as a propellant that has led to the adoption of this powder for use in the small arms of the British Army. No commercial use has yet been made of cordite as a mere producer of heat; but there is an interesting suggestion of possible future uses in the fact that crystals of diamond have been found in the residue of the explosion chamber—microscopic in size, to be sure, but veritable diamonds in miniature. Sir William Crookes has suggested that, could the reaction be prolonged sufficiently, "there is little doubt that the artificial formation of diamonds would soon pass from the microscopic stage to a scale more likely to satisfy the requirements of science, if not those of personal adornment."

OTHER INDUSTRIAL PROBLEMS OF TO-DAY AND TO-MORROW

In attempting to suggest the importance of science in its relation to modern industries, I have thought it better to cite three or four illustrative cases in some detail rather than to attempt a comprehensive summary of the almost numberless lines of commercial activity that have a similar origin and dependence.

To attempt a full list of these would be virtually to give a catalogue of mechanical industries. It may be well, however, to point out a few familiar instances, in order to emphasize the economic importance of the subject; and to suggest a few of the lines along which present-day investigators are seeking further conquests.

Very briefly, then, consider how the application of scientific knowledge has changed the aspect of the productive industries. Thanks to science, farming is no longer a haphazard trade. The up-to-date farmer knows the chemical constitution of the soil; understands what constituents are needed by particular crops and what fertilizing methods to employ to keep his land from deteriorating. He knows how to select good seed according to the teaching of heredity; how to combat fungoid and insect pests by chemical means; how to meet the encroachments of the army of weeds. In the orchard, he can tell by the appearance of leaf and bark whether the soil needs more of nitrogen, of potash, or of humus; he uses sprays as a surgeon uses antiseptics; he introduces friendly insects to prey on insect pests; he irrigates or surface-tills or grows cover crops in accordance with a good understanding of the laws of capillarity as applied to water in the earth's crust. In barnyard and dairy he applies a knowledge of the chemistry of foods in his treatment of flock and herd; he ventilates his stables that the stock may have an adequate supply of oxygen; he milks his cows with a mechanical apparatus, extracts the cream with a centrifugal "separator," and churns by steam or by electric power.

In the affairs of manufacturer and transporter of commodities, methods are no less revolutionary. Steam power and electric dynamo everywhere hold sway; trolley and electric light and telephone have found their way to the most distant hamlet; electricians and experimental chemists are searching for new methods in the factories; artificial stone is competing with the product of the quarries; artificial dyes have sounded the doom of the madder and indigo industries.

And yet it requires no great gift of prophecy to see that what has been accomplished is only an earnest of what is to come in the not distant future. In every direction eager experimenters are on the track of new discoveries. Any day a chance observation may open new and important fields of exploration, just as Hall's observation about the power of cryolite to absorb aluminum pointed the way to the new aluminum industry; and as Birkeland's chance observation of the electric arc in a magnetic field unlocked the secret of the unresponsive nitrogen. It will probably not be long, for example, before a way will be found to produce electric light without heat—in imitation of the wonderful lamp of the glow-worm.

Then in due course we must learn to use fuel without the appalling waste that at present seems unavoidable. A modern steam-engine makes available only five to ten per cent. of the energy that the burning fuel gives out as heat—the rest is dissipated without serving man the slightest useful purpose. Moreover, the new studies in radio-activity have taught us that every molecule of matter locks up among its whirling atoms and corpuscles a store of energy compared with which the energy of heat is but a bagatelle. It is estimated that a little pea-sized fragment of radium has energy enough in store—could we but learn to use it—to drive the largest steamship across the ocean —taking the place of hundreds of tons of coal as now employed. The mechanics of the future must learn how to unlock this treasury of the molecule; how to get at these atomic and corpuscular forces, the very existence of which was unknown to science until yesterday. The generation that has learned that secret will look back upon the fuel problems of our day somewhat as we regard the flint and steel and the open fire of the barbarian.

If problems of energy offer such alluring possibilities as this, problems of matter are even more inspiring. The new synthetic chemistry sets no bounds to its ambitions. It has succeeded in manufacturing madder, indigo, and a multitude of minor compounds. It hopes some day to manufacture rubber, starch, sugar—even albumen itself, the very basis of life. Rubber is a relatively simple compound of hydrogen and carbon; starch and sugar are composed of hydrogen, carbon, and oxygen; albumen has the same constituents, plus nitrogen. The raw materials for building up these substances lie everywhere about us in abundance. A lump of coal, a glass of water, and a whiff of atmosphere contain all the nutritive elements, could we properly mix them, of a loaf of bread or a beefsteak. And science will never rest content until it has learned how to make the combination. It is a long road to travel, even from the relatively advanced standpoint of to-day; but sooner or later science will surely travel it.

And then—who can imagine, who dare predict, the social and economic revolution that must follow? Our social and business life to-day differs more widely from that of our grandfathers than theirs differed from the life of the Egyptian and Babylonian of three thousand years ago; but this gap is as ditch to cañon compared with the gap that separates us from the life of that generation of our descendants which shall have learned the secret of making food-stuffs from inorganic matter in the laboratory and factory. It is a long road to travel, I repeat; but modern science travels swiftly and with many short-cuts, and it may reach this goal more quickly than any conservative dreamer of to-day would dare to predict.

All speed to the ambitious voyager!

APPENDIX

REFERENCE LIST AND NOTES

CHAPTER I

MAN AND NATURE

For a general discussion of primitive conditions of labor and prehistoric man's civilization, it will be of interest in connection with this chapter to consult volume I., chapter I., which deals with prehistoric science. The appendix notes on that chapter (vol. I., pp. 302, 303) refer to some books which may be consulted for fuller information along the same lines.

CHAPTER II

HOW WORK IS DONE

(p. 31). For study of Archimedes, giving a detailed account of his discoveries, see vol. I., p. 196 *seq.* It will be of interest also to review, in connection with this chapter, the story of the growth of knowledge of mechanics in the time of Galileo, Descartes, and Newton as told in the chapters entitled "Galileo and the New Physics," vol. II. (p. 93 *seq.*), and "The Success of Galileo in Physical Science," vol. II., p. 204 *seq.*

CHAPTER III

THE ANIMAL MACHINE

For further insight into the activities of the animal machine, the reader may refer to various chapters on the progress of physiology and anatomy in earlier volumes. The following references will guide to the accounts of the successive advances from the earliest time:

Vol. I., pp. 194, 195 describe briefly the earlier anatomical studies of the Alexandrian physicians, Herophilus and Erasistratus; and pp. 282, 283, outline the studies of the famous physician, Galen.

Vol. II., "From Paracelsus to Harvey," in particular, p. 163 *seq;* and chapters IV. (p. 173 *seq.*) and V. (p. 202 *seq.*) dealing with the progress of anatomy and physiology in the eighteenth and nineteenth centuries respectively. The chapter on "Experimental Psychology" (p. 245 *seq.*) may also be consulted.

Vol. V., chapter V., dealing with the Marine Biological Laboratory at Naples (p. 113 *seq.*) and chapter VI., "Ernst Haeckel and the New Zoology" (p. 144 *seq.*) present other aspects of physiological problems.

CHAPTER IV

THE WORK OF AIR AND WATER

On page 63 reference is made to the work of the old Greeks, Archimedes and Ctesibius. An account of Archimedes' discovery of the laws of buoyancy of solids and liquids will be found in vol. I., p. 208.

(p. 64). The machines of Ctesibius and Hero. See vol. I., p. 242 *seq.*, for a full account of these mechanisms.

(p. 65). Toricelli, the pupil of Galileo, and his discovery of atmospheric pressure. For a fuller account of his discovery and what came of it see vol. II., p. 120 *seq.*

(p. 66). Boyle's experiments on atmospheric pressure. See vol. II., p. 204 *seq.*

(p. 66). Mariotte and Von Guericke. See vol. II., p. 210 *seq.*

(p. 71). Roman mills. A scholarly discussion of the subject of Roman mills, based on a comprehensive study of the references in classical literature, is given in Beckmann's *History of Inventions*, London, 1846.

(p. 73). Recent advances in water wheels. As stated in the text, the quotation is from an article on *Motive Power Appliances*, by Mr. Edward H. Sanborn, in the *Twelfth Census Report* of the United States.

CHAPTER V

CAPTIVE MOLECULES; THE STORY OF THE STEAM-ENGINE

(p. 82). The experiments of Hero of Alexandria. For a full account of the experiments see vol. I., pp. 249, 250.

(p. 84). The Marquis of Worcester's steam engine. The original account appeared, as stated, in the Marquis of Worcester's *Century of Inventions*, published in 1663.

(p. 92). Newcomen's engine. As stated in the text, the account of Newcomen's engine is quoted from the report of the Department of Science and Arts of the South Kensington Museum, now officially known as the Victoria and Albert Museum.

(pp. 107–109). James Watt. The characterization of Watt here given is taken from an article in an early edition of the Edinburgh Encyclopædia published about the year 1815.

CHAPTER VI

THE MASTER WORKER

(p. 112). High-pressure steam. The work referred to is Leupold's *Theatrum Machinarum*, 1725.

(p. 122). Rotary Engines. The quotation is from the report of the Victoria and Albert Museum above cited.

(pp. 127, 128). Turbine engines. The quotation is from an anonymous article in the London *Times*, August 14, 1907.

(pp. 129, 130). Turbine engines. The quotation is from an article on *Motive Power Appliances* in the *Twelfth Census Report* of the United States, vol. X., part IV., by Mr. Edward H. Sanborn.

CHAPTER VII

GAS AND OIL ENGINES

(pp. 135, 136, 137). Gas engines. Quoted from the report of the Victoria and Albert Museum above cited.

(pp. 141–144). Gas engines and steam engines in the United States. Quoted from the report of the Special Agents of the *Twelfth Census* of the United States, 1902.

(pp. 146, 147). The Svea heater. From an article by Mr. G. Emil Hesse in *The American Inventor* for April 15, 1905.

CHAPTER VIII

THE SMALLEST WORKERS

In connection with this chapter the reader will do well to review various earlier portions of the work outlining the general history of the growth of knowledge of electricity and magnetism. For example:

Vol. II., p. 111 *seq.*, for an account of William Gilbert's study of magnetism; pp. 213, 215 describing first electrical machine; and chapter XIV., "The Progress of Electricity from Gilbert and Von Guericke to Franklin," p. 259 *seq.*

Vol. III., chapter VII., "The Modern Development of Electricity and Magnetism," p. 229 *seq.*

Vol. V., p. 92 *seq.*, the section on Prof. J. J. Thompson and the nature of electricity.

Other chapters that may be advantageously reviewed in connection with the present one are the following:

Vol. III., chapter VI., "Modern Theories of Heat and Light," p. 206 *seq.;* chapter VIII., "The Conservation of Energy," p. 253 *seq.;* and chapter IX., "The Ether and Ponderable Matter," p. 283 *seq.*

CHAPTER IX

MAN'S NEWEST CO-LABORER: THE DYNAMO

The references just given for chapter VIII. apply equally here.

The experiments of Oersted and Faraday are detailed in vol. III., p. 236 *seq.*

CHAPTER X

NIAGARA IN HARNESS

Same references as for chapters VIII. and IX.

CHAPTER XI

THE BANISHMENT OF NIGHT

(p. 221). Davy and the electric light. The quotation here given is reproduced from vol. III., pp. 234, 235. The very great importance and general interest of the subject seem to justify the repetition, descriptive of this first electric light. Davy's original paper was given at the Royal Institution in 1810.

(p. 237). "Peter Cooper Hewitt—Inventor," by Ray Stannard Baker, in *McClure's Magazine*, June, 1903, p. 172.

In connection with the problem of color of the light emitted by

Mr. Hewitt's mercury-vapor tube, the chapter on "Newton and the Composition of Light" (vol. II., p. 225 *seq.*) may be consulted. Also "Modern Theories of Heat and Light," vol. III., p. 206 *seq.*

CHAPTER XII

THE MINERAL DEPTHS

The chapter on "The Origin and Development of Modern Geology," vol. III., p. 116 *seq.*, may be read in connection with the allied subjects here treated.

In preparing the section on the use of electricity in mining, the article by Thomas Commerford Martin, entitled *Electricity in Mining*, in the United States *Census Report* of 1905, has been freely drawn upon. The quotations on pp. 262, 266, 268, and 270 are from that source.

CHAPTER XIII

THE AGE OF STEEL

See note under chapter XII.

CHAPTER XIV

SOME RECENT TRIUMPHS OF APPLIED SCIENCE

In connection with various portions of this chapter the reader will find much that is of interest in the story of chemical development in general as detailed in volume III., pp. 3–72 inclusive.

Also various chapters on electricity as outlined under chapter VII. above.

(p. 310). Nitrogen from the air. The quotation is from the *Engineering Supplement* of the London *Times*, January 22, 1908.

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